JOURNAL OF THE IRON AND STEEL INSTITUTE

MARCH 1961

Volume 197 Part 3

Established 1869

Incorporated by Royal Charter 1899

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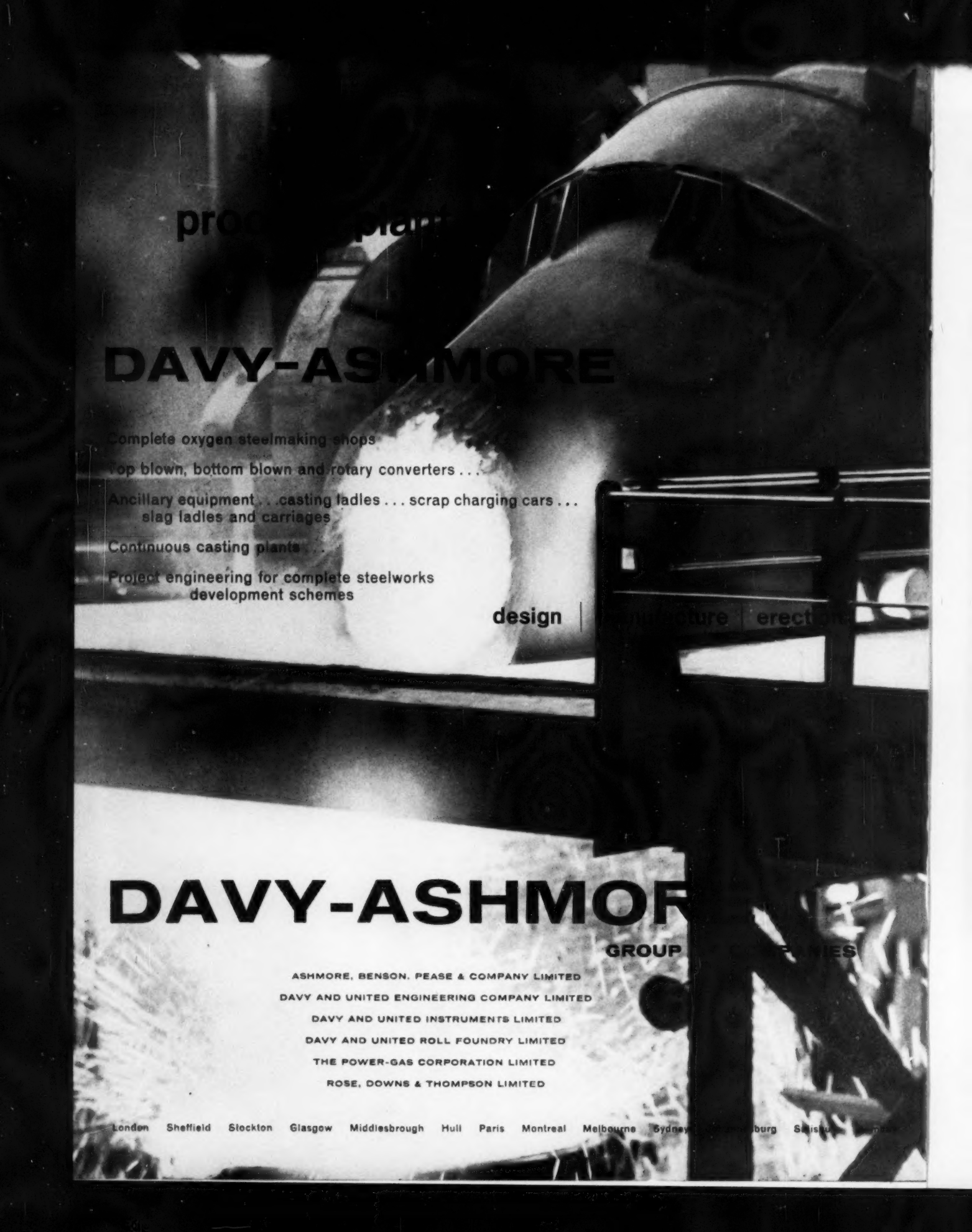
DAVY-ASHMORE
Complete oxygen steelmaking shops
Top blown, bottom blown and rotary converters . . .
Ancillary equipment . . casting ladles . . . scrap charging cars . . .
slag ladles and carriages
Continuous casting plants . . .
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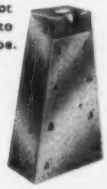
Covered by British Patent No.'s 546,220 and 749,491

FERROCLIP SUSPENSION

This method allows the brick to be suspended from the end. The Ferroclip hanger slot may be moulded into any roof or wall shape.

Covered by British Patent No.'s 546,220 and 600,630



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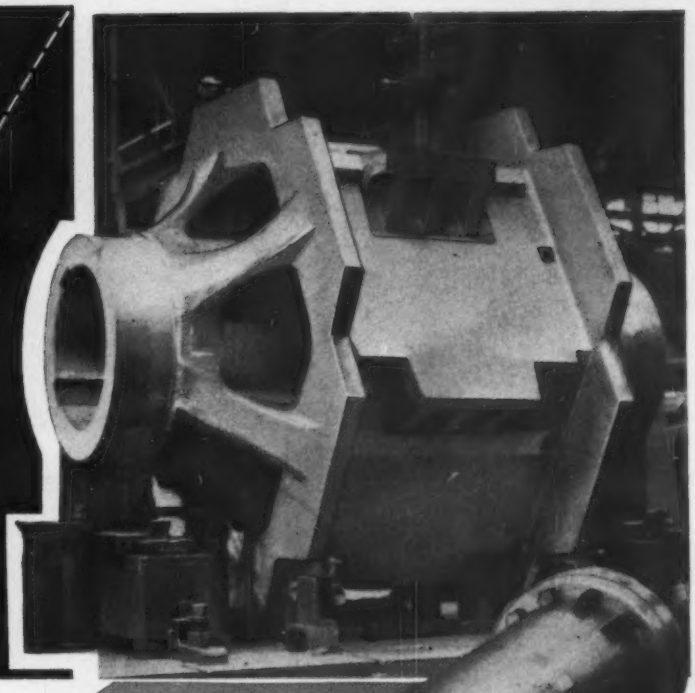

Top tumbler for ore dredging. Weight 17½ tons

...lity steel castings ...any applications ...ffer certain econ... advantages over ... production ...ods. Before final... your requirements ...INK OF CASTINGS FIRST ... consult Hadfields ... name celebrated for ...eels in CARBON—LOW ...LOY—STAINLESS— ...ANGANESE—WEAR ...ESISTING—HEAT ...RESISTING STEELS.

Tilting cylinder assembly. Weight 18 tons

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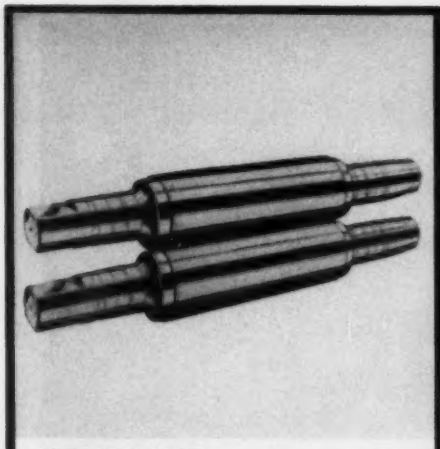
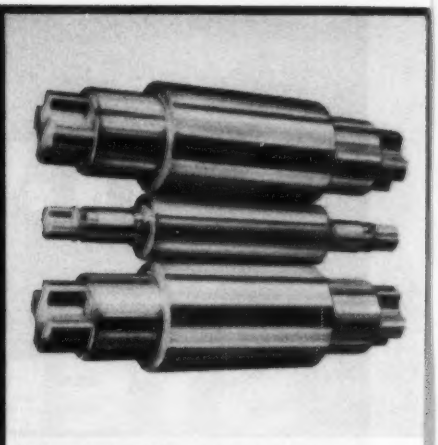


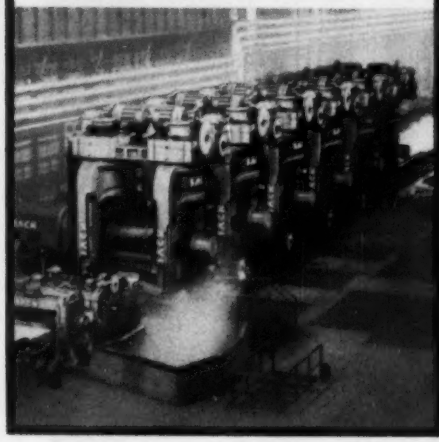
Work rolls 27" x 83"

4-high plate mill

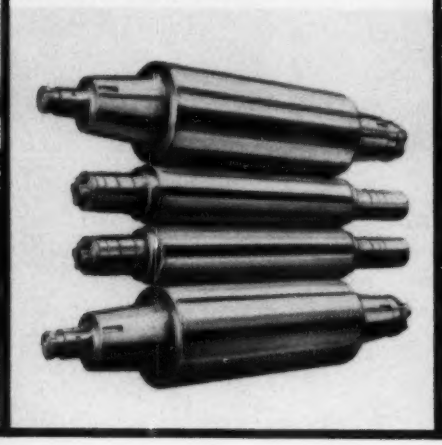


Rolls 32" x 53 1/2" and 20" x 59 1/2"

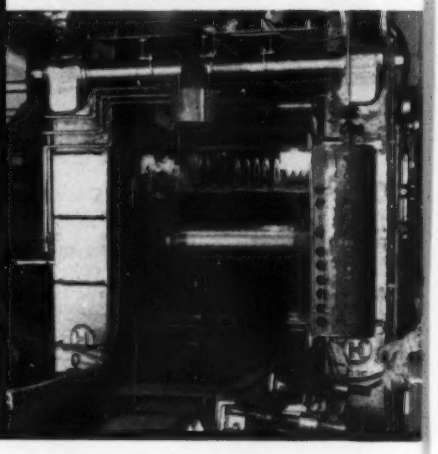
Continuous finishing train in a wide strip mill



Work rolls 35 1/2" x 150"



3-high roughing stand for sheet



Åkers rolls for plate and strip steel give lower costs per rolled unit

AB Åkers Styckebruk manufactures rolls for hot rolling in e. g. *Plate Mills, Roughing Mills for Sheet, Steckel Hot Strip Mills and Mills for Wide and Narrow Strip Steel.*
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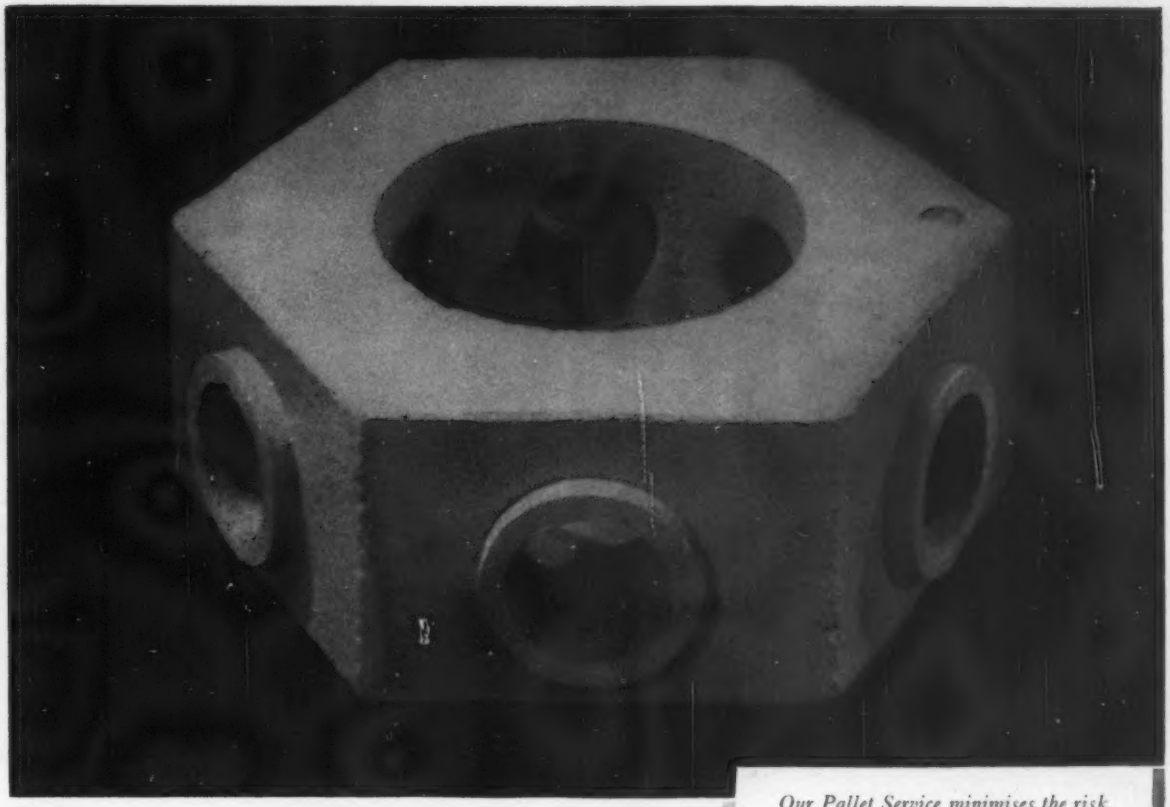

Centre of attraction

To the expert's discerning eye, a centre brick made by Wraggs of Sheffield represents all that's finest in casting pit refractory manufacture. In addition to perfect external shape and accuracy of dimensions, the smooth internal finish ensures that no refractory inclusions are picked up by the metal during pouring.

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-:-:-:-ebbw Vale electrolytic tinning plant £2
-:-:-:-poland hot dip tinning line £180,000 :-
aviles blast furnace and sinter plant £6,000,000 :-
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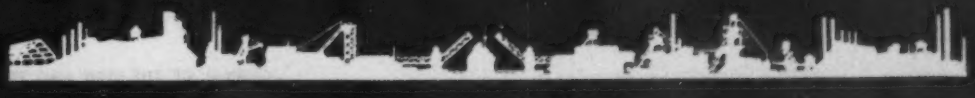
specialised rolling stock more than £1,000,000



Allied with the new Tigerschiold method of hot-top manufacture, the CO_2/silicate process enables you to cut your costs dramatically. The Tigerschiold method — easy to apply, and giving speedier production, greater ingot yield, and longer mould life — uses the CO_2/silicate process exclusively. The British patent rights to the CO_2/silicate process are held by I.C.I., and I.C.I. technical service — already well known in the foundry trade — is freely available to customers.

Enquire at your nearest I.C.I. sales office for further details.

British licensee of the Tigerschiold method (Brit. Pat. No. 778,039) is Hinckley's Ltd., Sheffield 7. The CO_2/silicate process is protected by Brit. Pat. No. 654,817.

I.C.I. products for the CO_2/silicate process

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New Hot-top method reduces steel-making costs!

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FLYING SAUCERS

This saucer shaped cargo is a stainless steel spun head made from Colclad, one of Colvilles special clad steels which has high corrosion resisting qualities. The saucer is 7′ in diameter, $\frac{3}{4}$″ thick and is over a ton in weight.

It is flying to Montreal where it and another like it will form part of an installation being built by Canadian Vickers Ltd.

By night and by day Colvilles steel is on the move to industrial projects all over the world.

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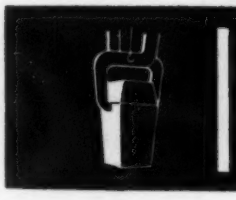

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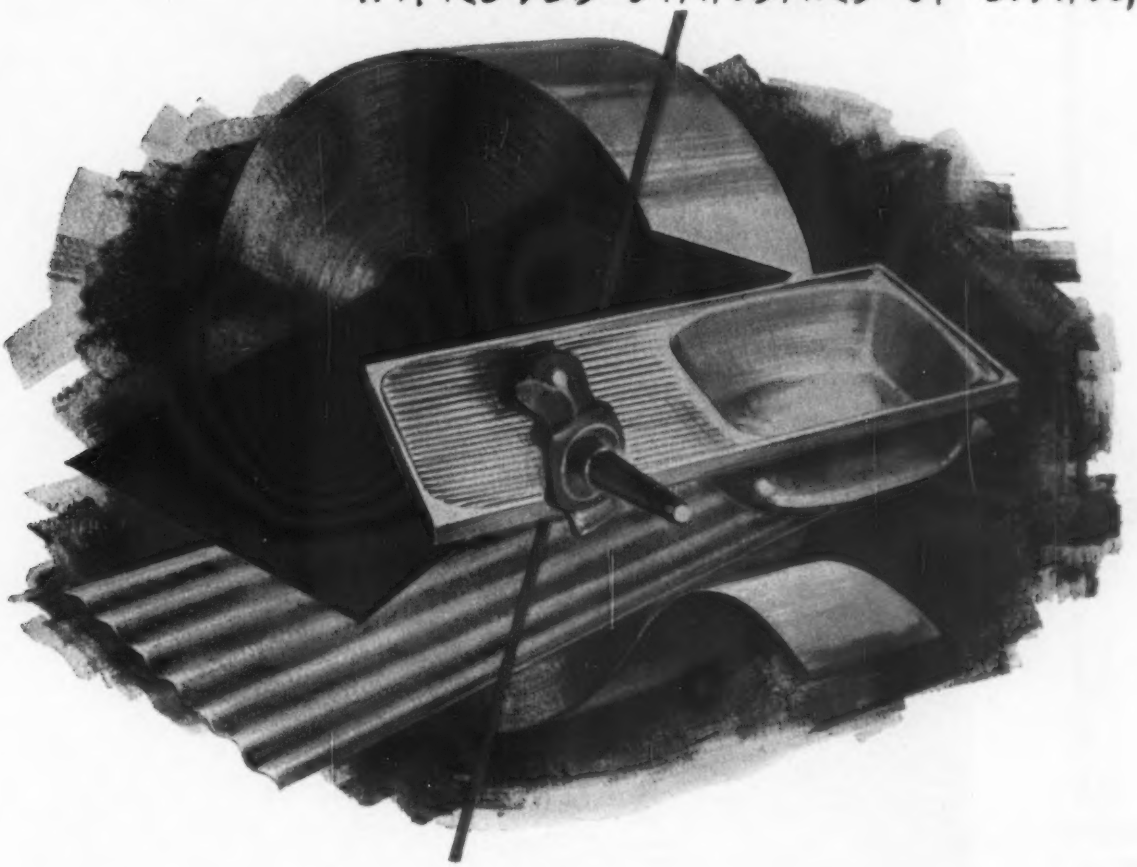

think of R·T·B

The artist's impression shows a forged motor-car stub axle, a stainless steel sink, blue planished sheet and some galvanized sheets against a coil of cold-reduced steel strip, all made by RTB or from RTB steel.

First in Europe to install a continuous wide-strip mill, RTB make steel that serves you in many ways.

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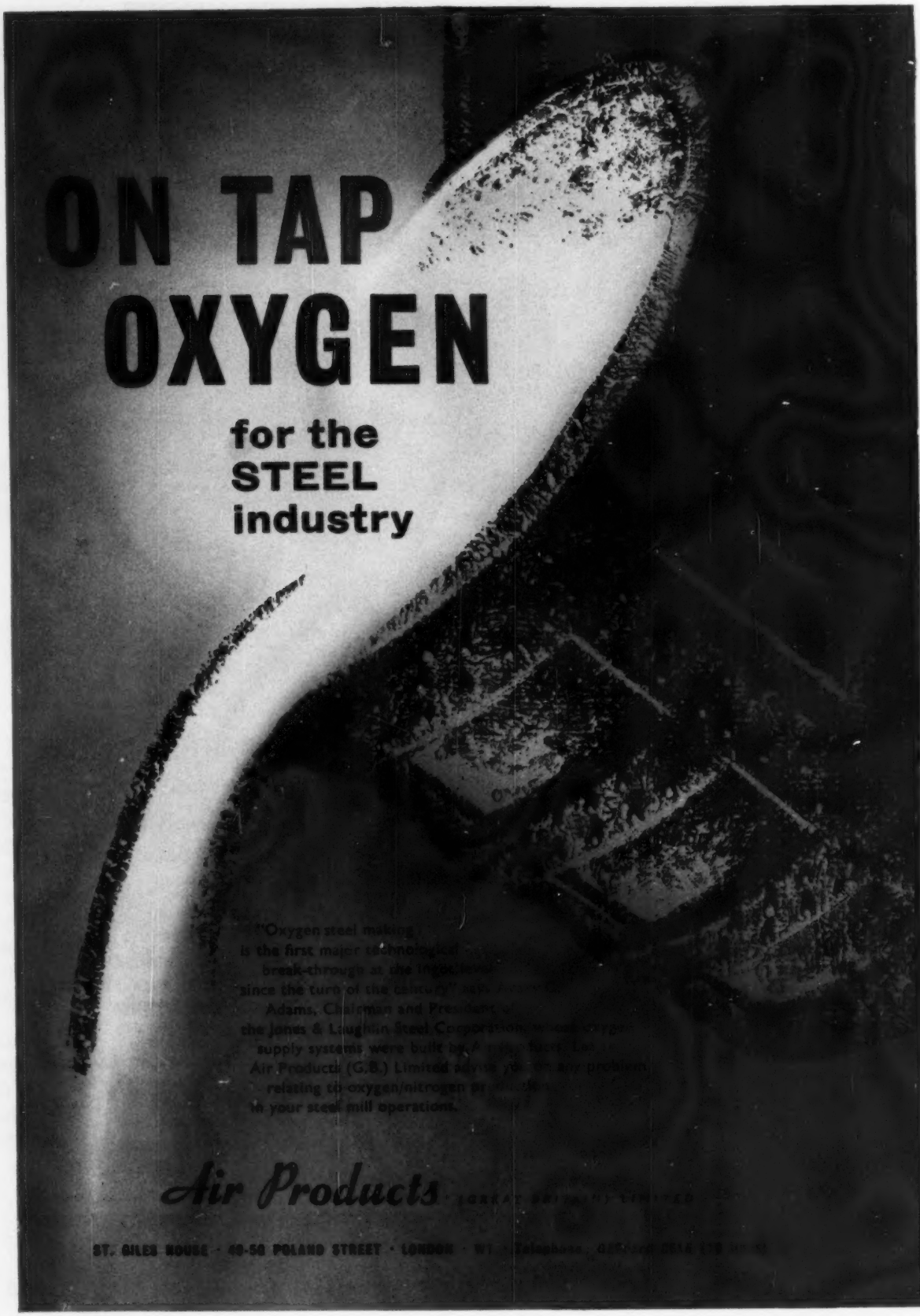
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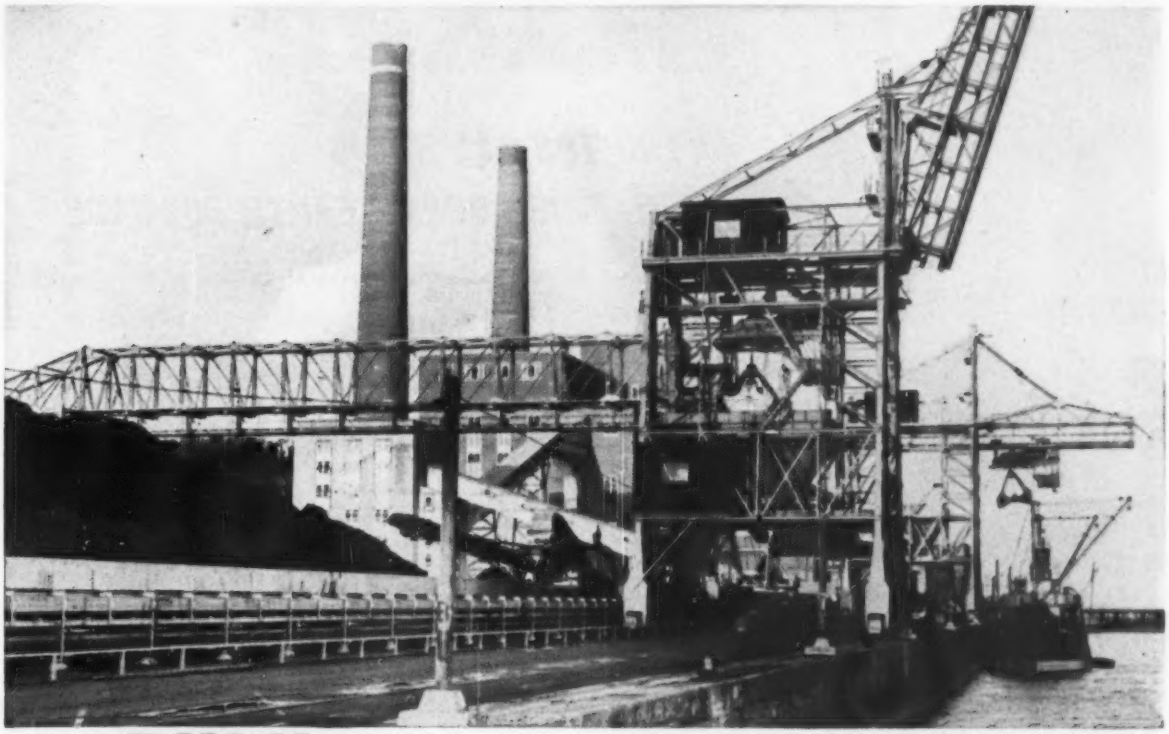
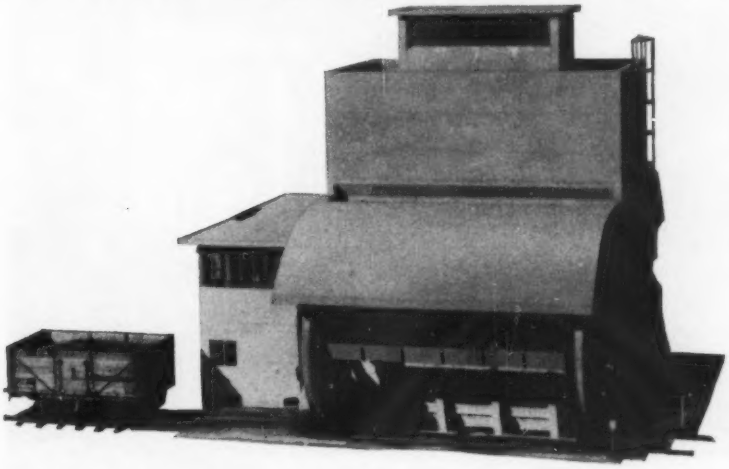


BULK HANDLING PLANT by STRACHAN & HENSHAW

The coal handling plant at the Portishead power station of the Central Electricity Generating Board incorporates:
two Ship Unloaders of 150 t.p.h. each: one Storage and Reclaiming Transporter (260 t.p.h.) two Rotaside Wagon Tipplers (with S & H patented Dust Trapping System). Wagon marshalling plant etc. One of the dust trapping Wagon Tipplers is shown below.



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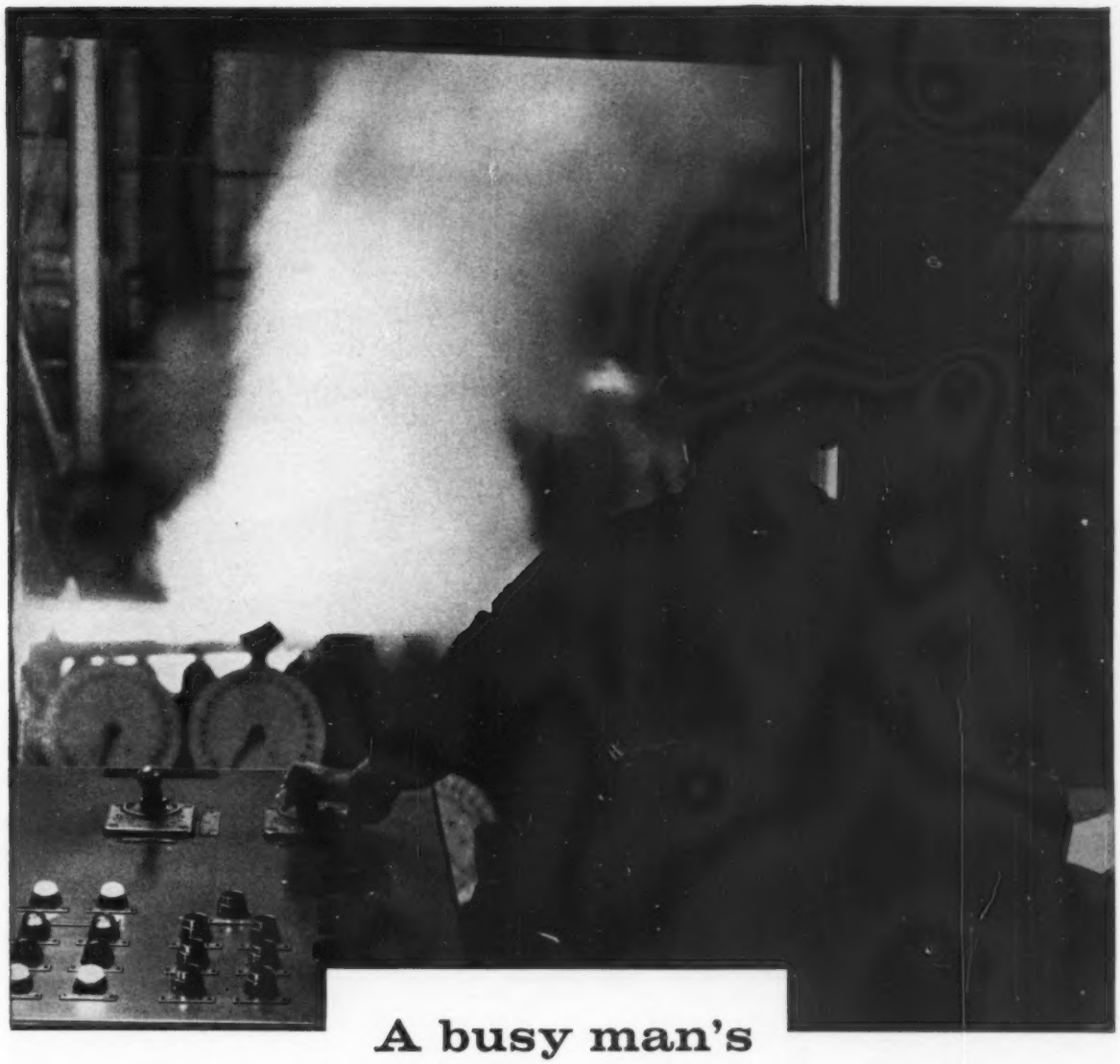

A busy man's guide to Britain's steel progress

WINSTON CHURCHILL kept his finger on the pulse of things by asking for important information "on one side of a sheet of paper".

The post-war achievements of the British steel industry would fill a book. Here, for the busy man whose eye we have this minute, is an account of what is happening now.

PRODUCTION The British steel industry produced over 24 million tons of steel in 1960 – compared with 20 million tons in 1959. Output is now about *double* the pre-war figure. Production of alloy steels – especially stainless steel – is expanding particularly rapidly.

PLANT Since the end of 1946, almost £900,000,000 has been spent on development. Continued modernisation and expansion – now costing some £130,000,000 a year – will provide steel capacity for over 34 million tons by 1965. Pig iron output per furnace and open hearth steel output per furnace are both more than double pre-war. With the need for ever-increasing efficiency and economy, ore beneficiation has made great strides and fuel consumption per ton of iron has been reduced by about 25% since the war. Use of oxygen for steelmaking is rapidly increasing.

INDUSTRIAL RELATIONS The industry keeps its remarkably good record for settling industrial disputes without recourse to strike action. British steel workers are often sons and grandsons of steel workers, richly endowed with traditional skills. Making steel exactly to specification is more than a commercial requirement; it's a matter of pride.

PRICES British steel prices have been keenly competitive since the war with those of other major European producers and well below the American price level – and the quality of British steel is unsurpassed.

THE BRITISH IRON AND STEEL FEDERATION

another THORNTON contract

however you look at it

YOU WILL agree that this Ingot Car is a nice job. Its sleek business-like lines commend it as a sound job, but it's only when you look underneath that you appreciate its truly functional design. Built with a wide margin of safety to carry four 5-ton ingots it will take a total superimposed load of 50 tons. This is one of many Ingot Casting Cars constructed to house automatic couplings and fitted with free running wheels on roller bearings and fixed axles.

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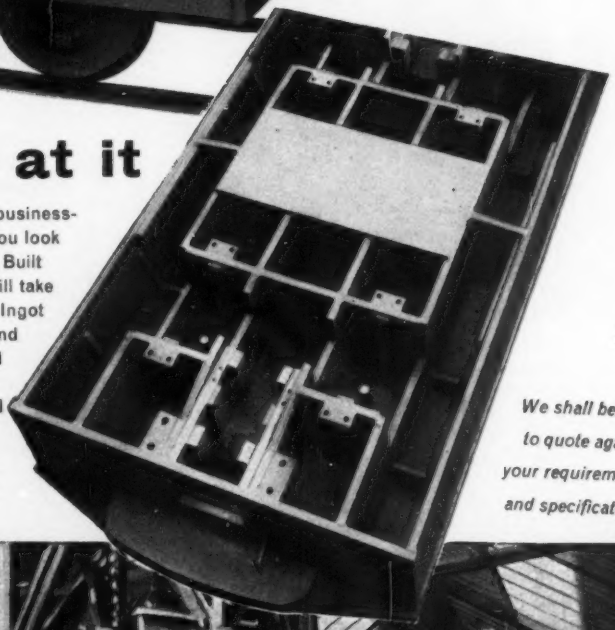

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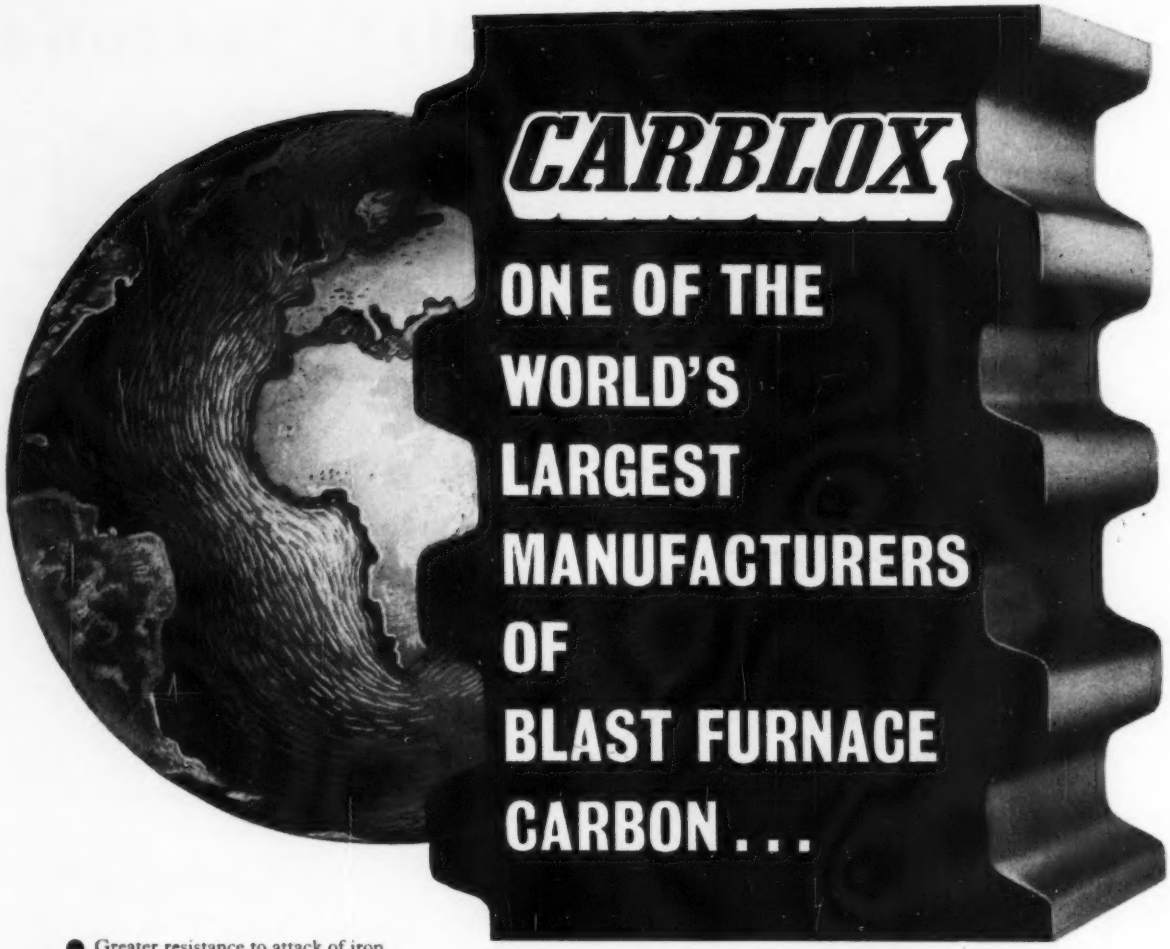

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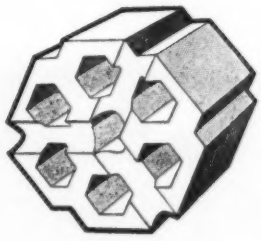

CARBLOX LIMITED now offer the TEMCO pattern chequer brick manufactured by our parent company, Thomas Marshall & Co, (Loxley Ltd. This new brick has an effective brick mass of 99%—much higher than any other type of chequer. Details sent on request.

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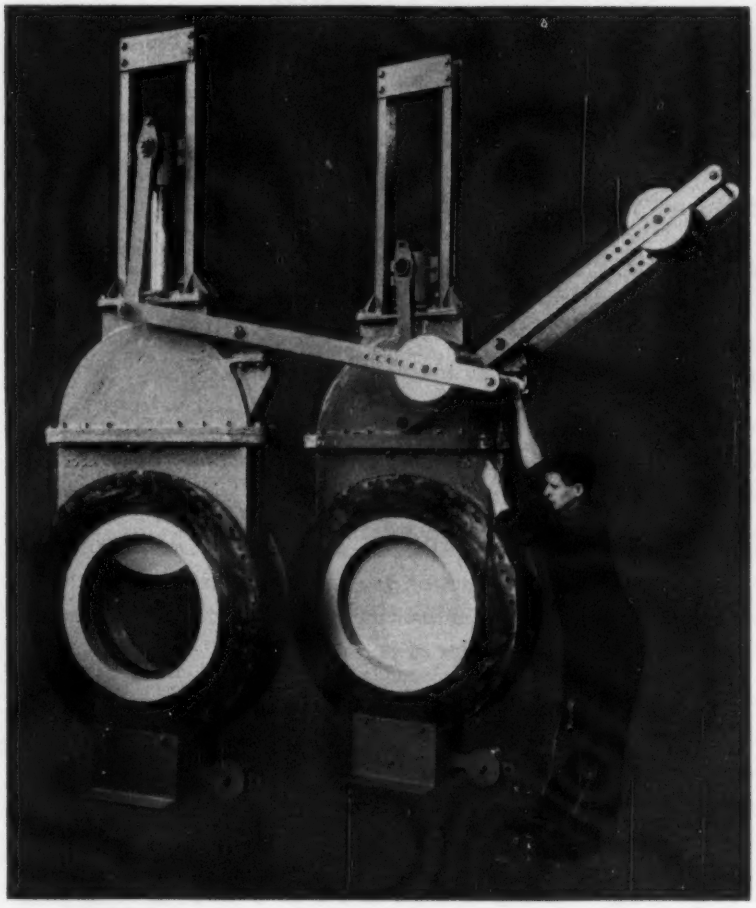

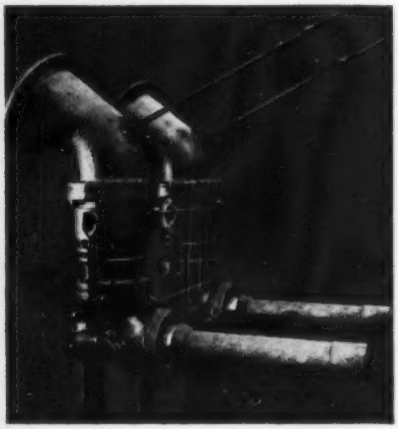

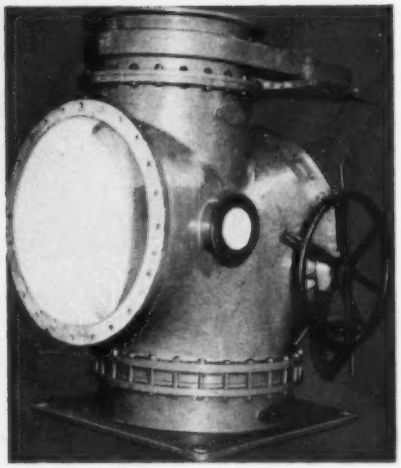

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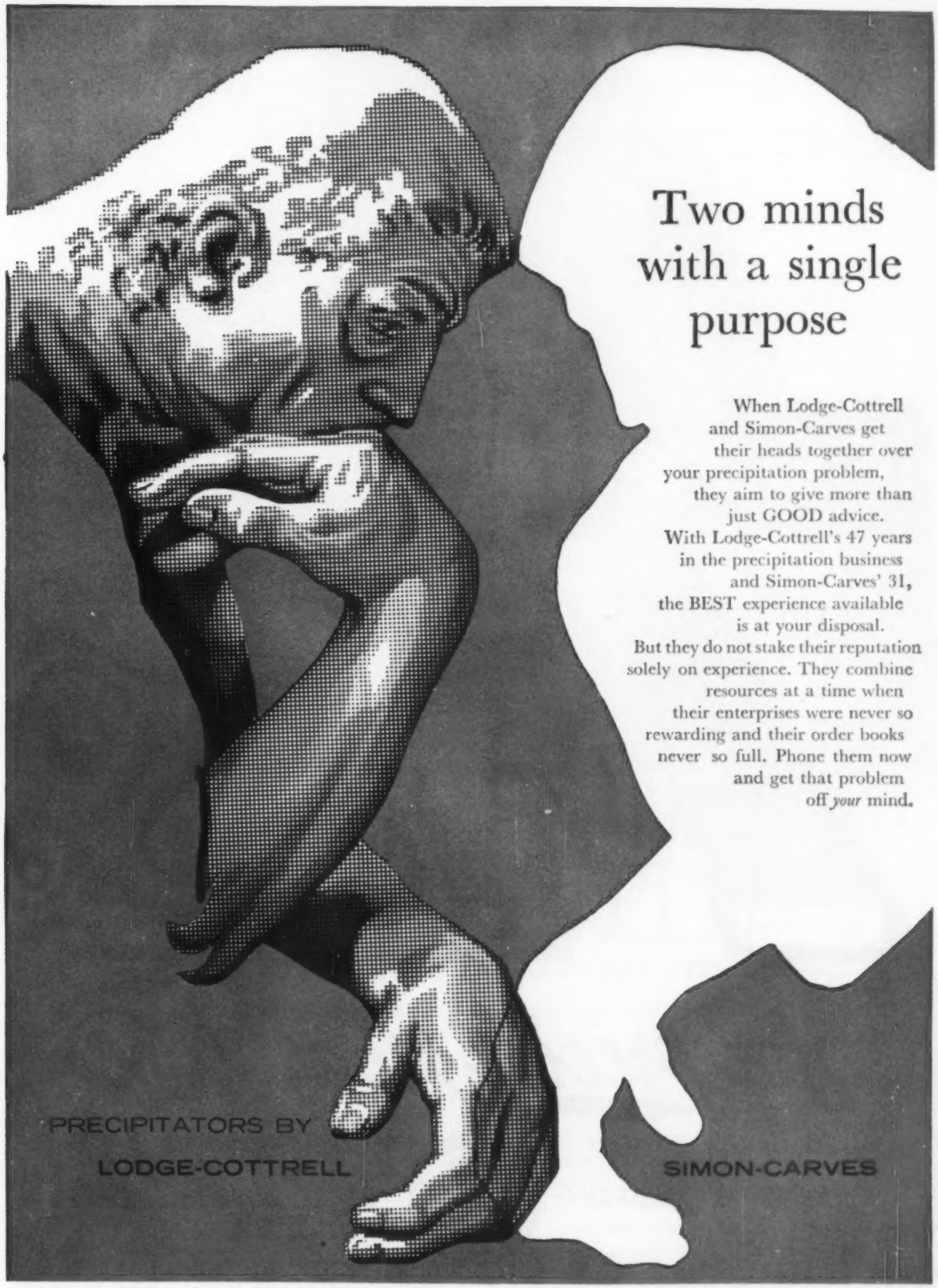

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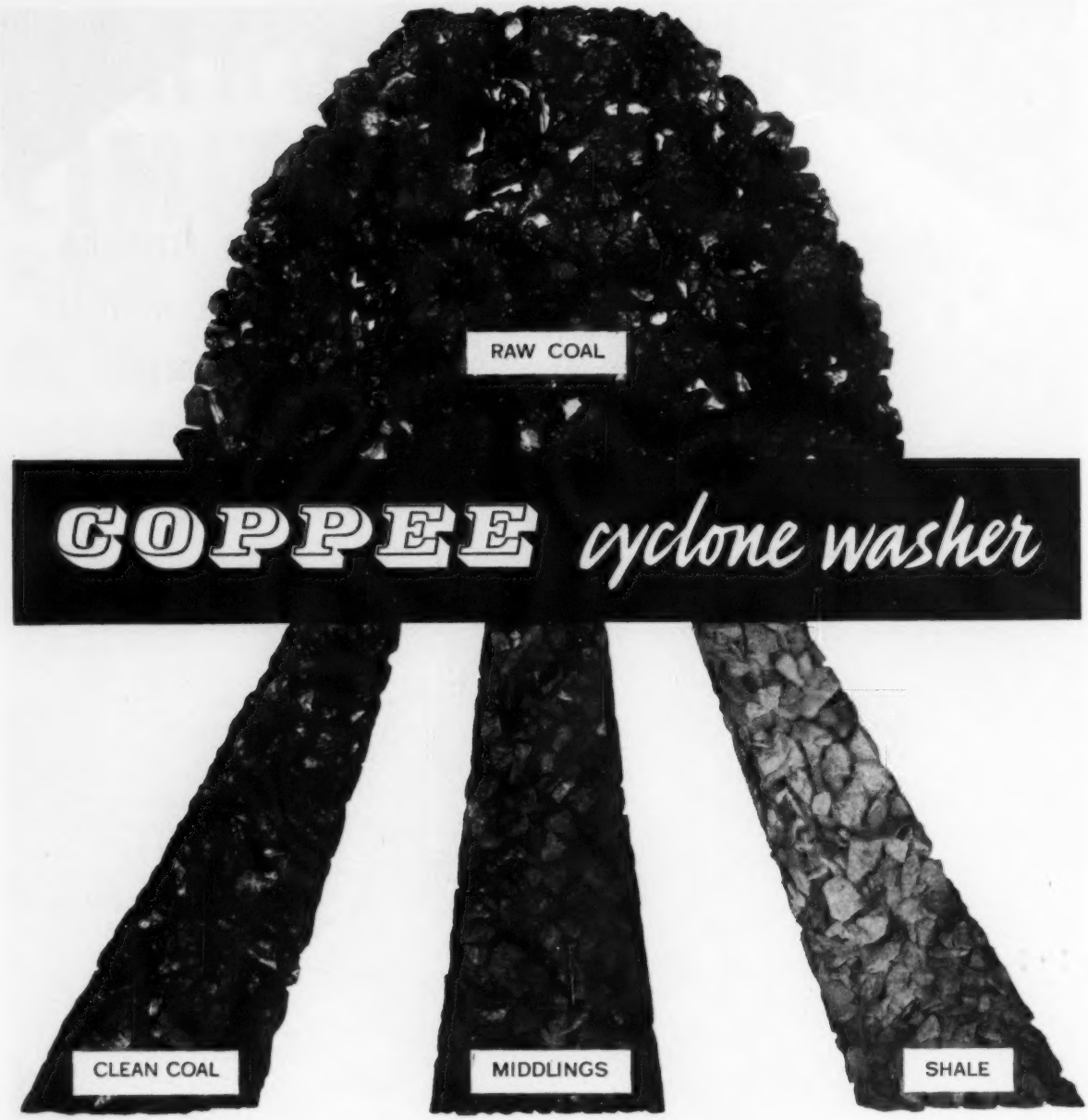

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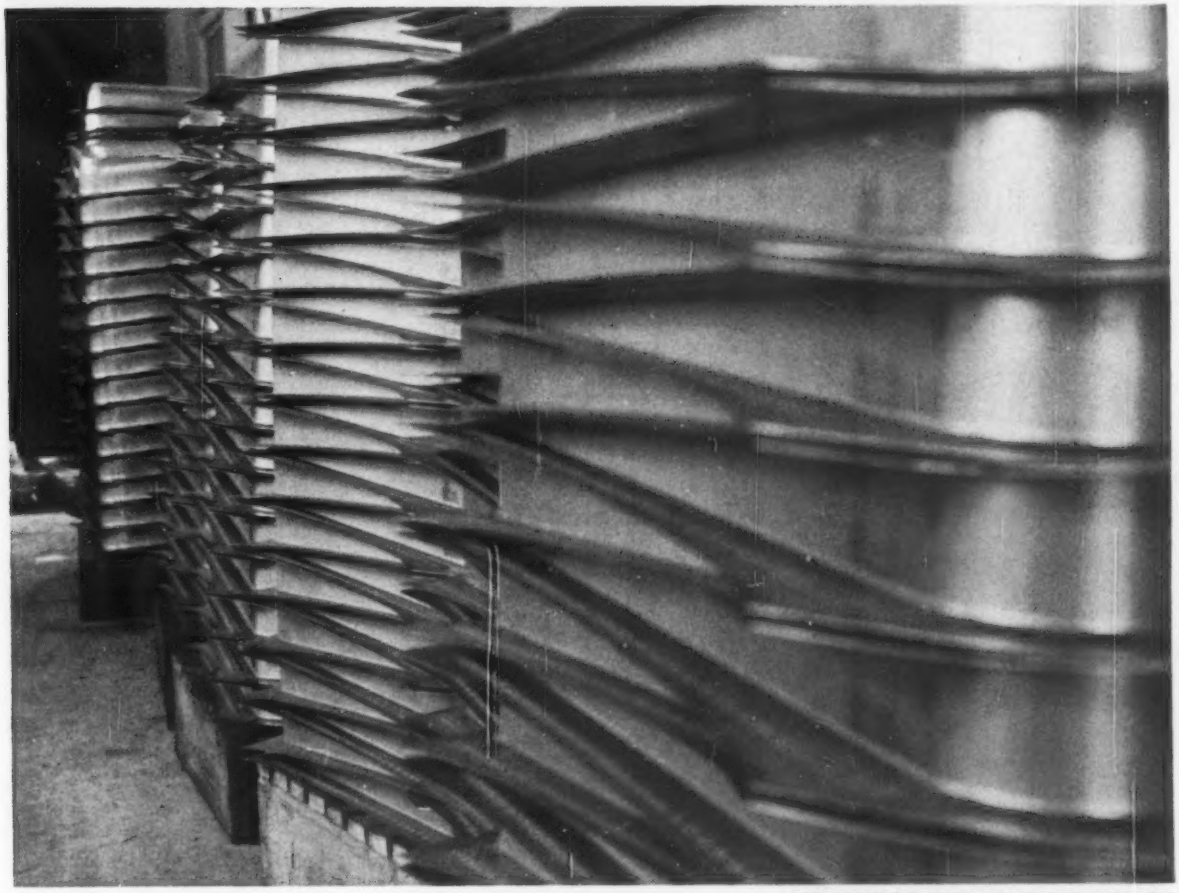

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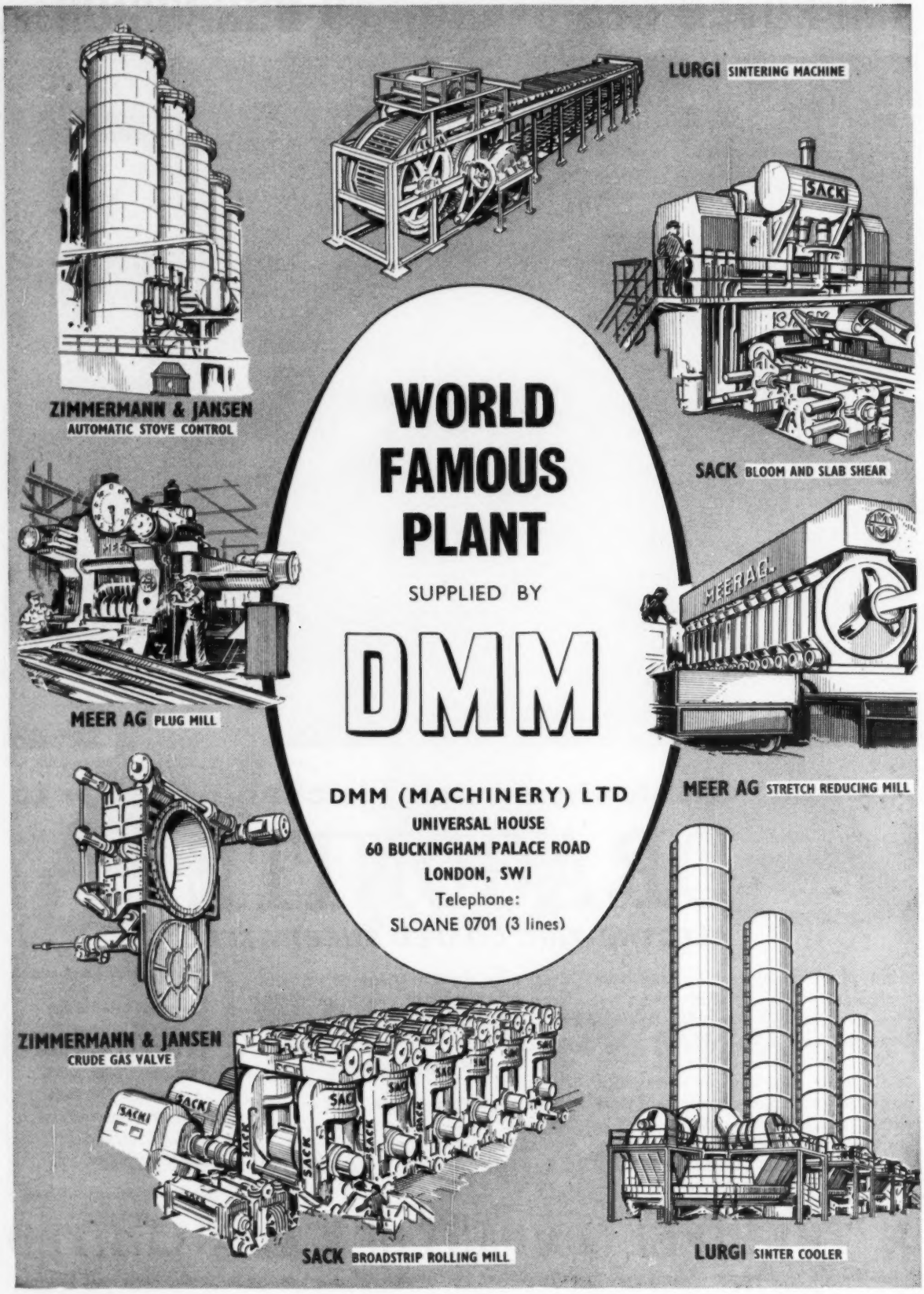
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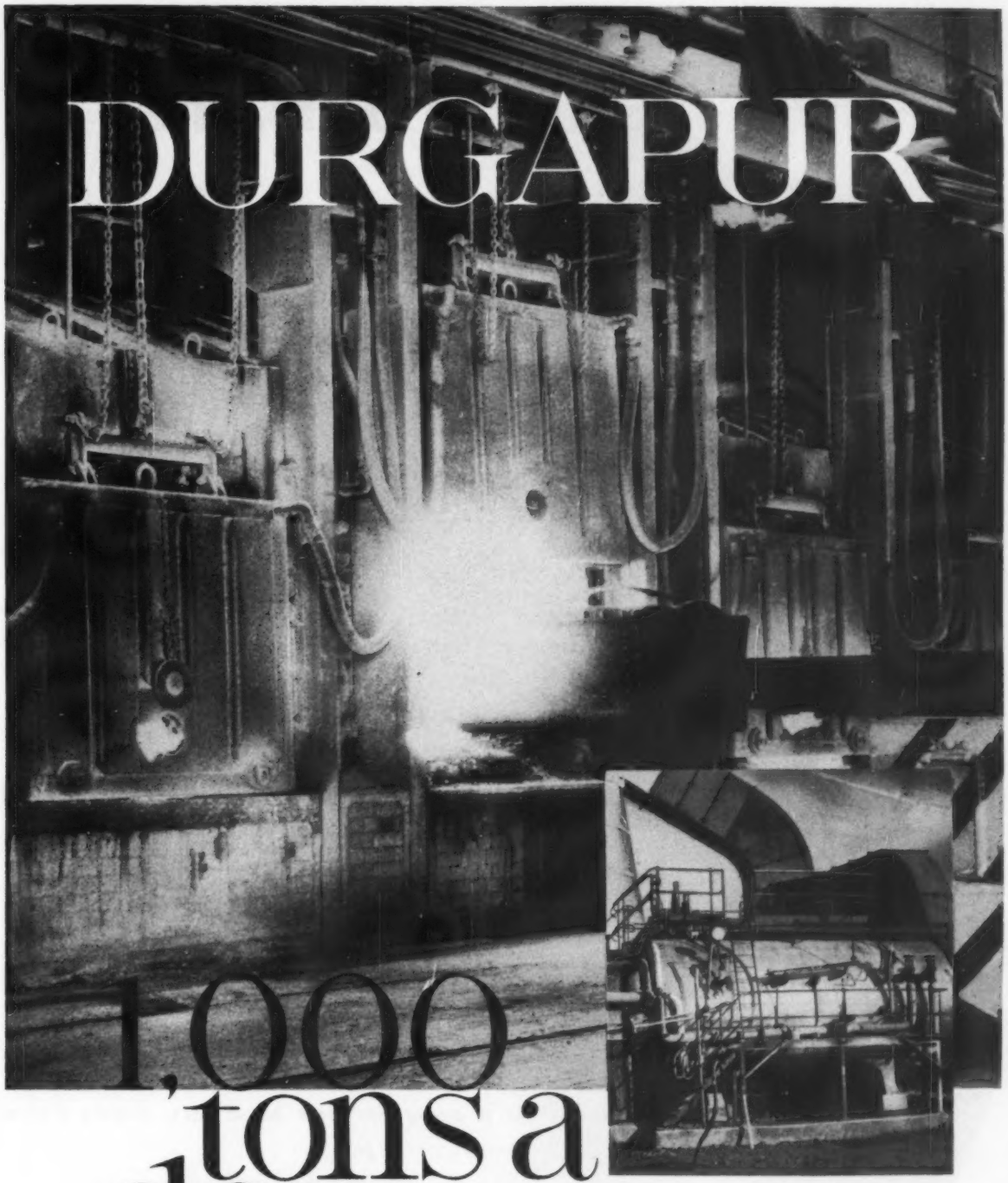

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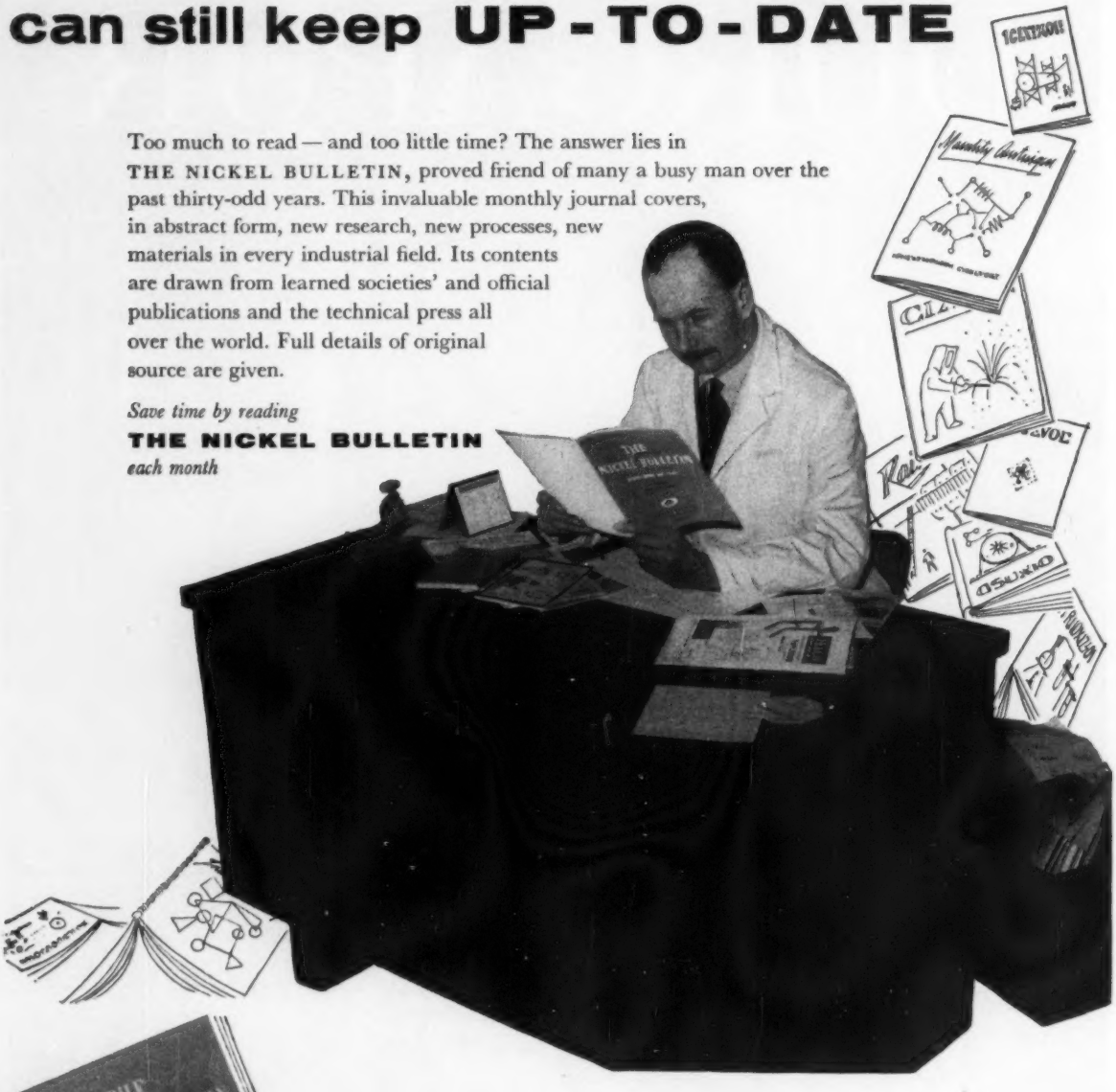

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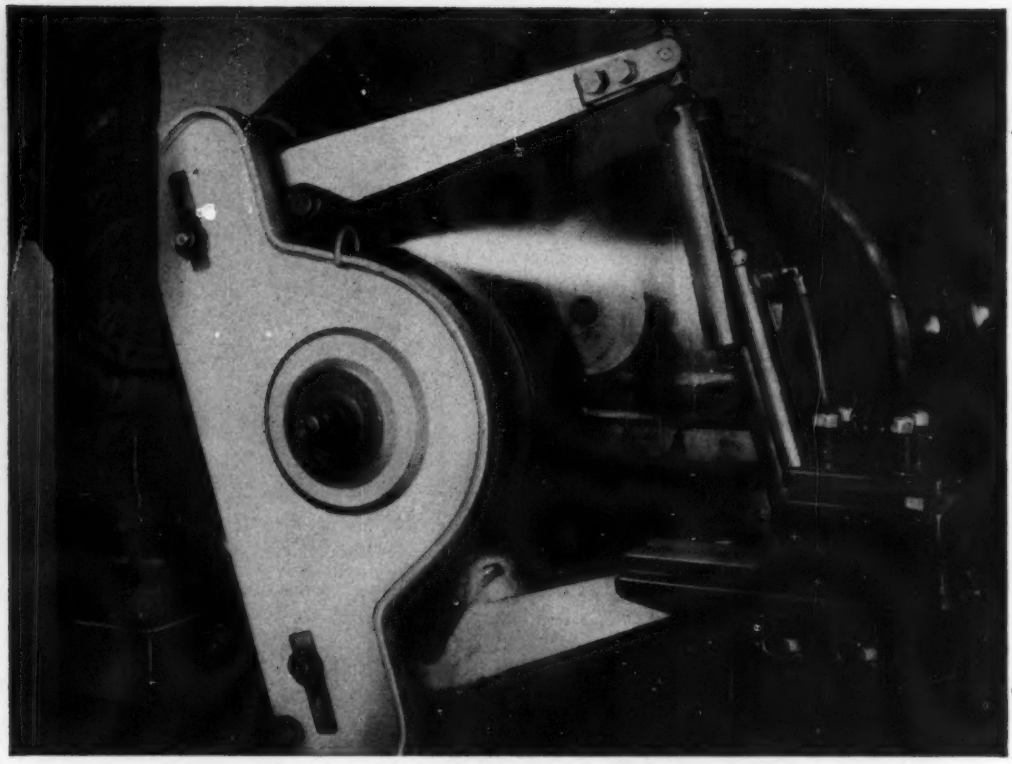

Wheel testing machine braking a solid wheel from high speed.

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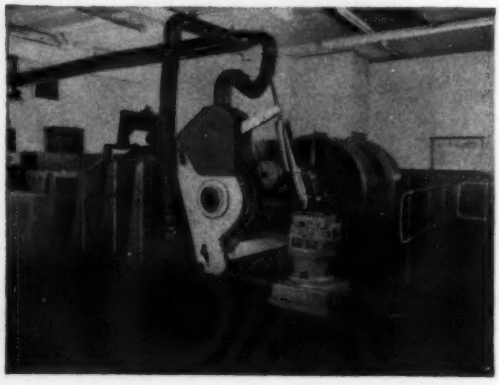

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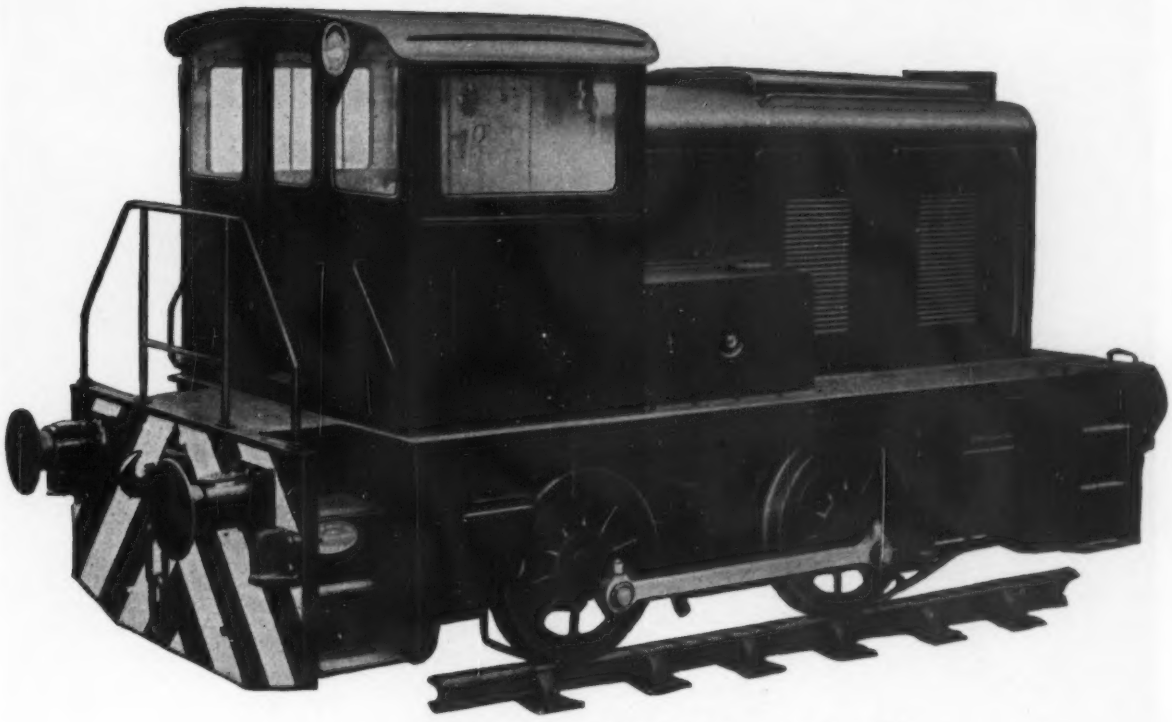

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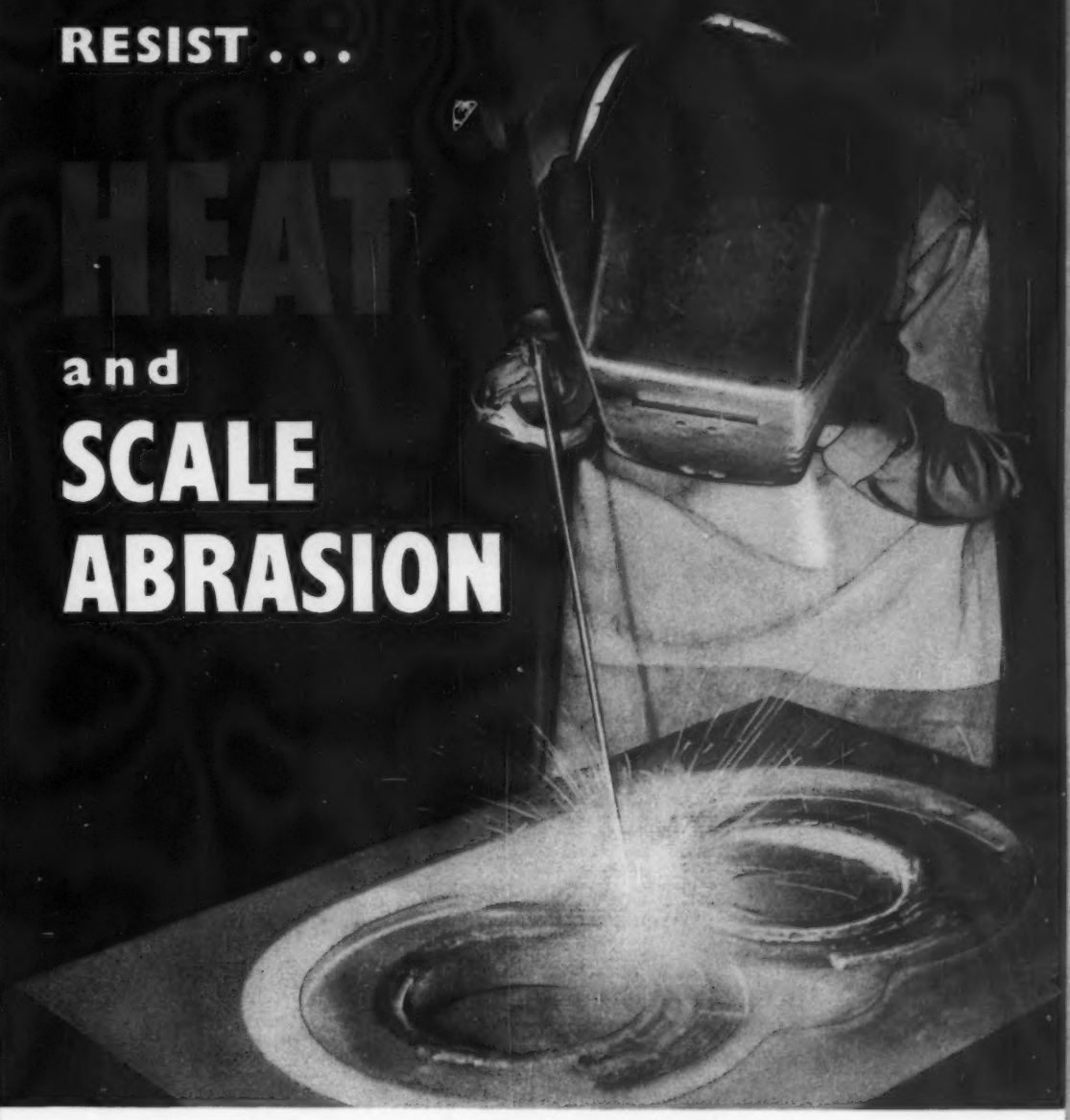

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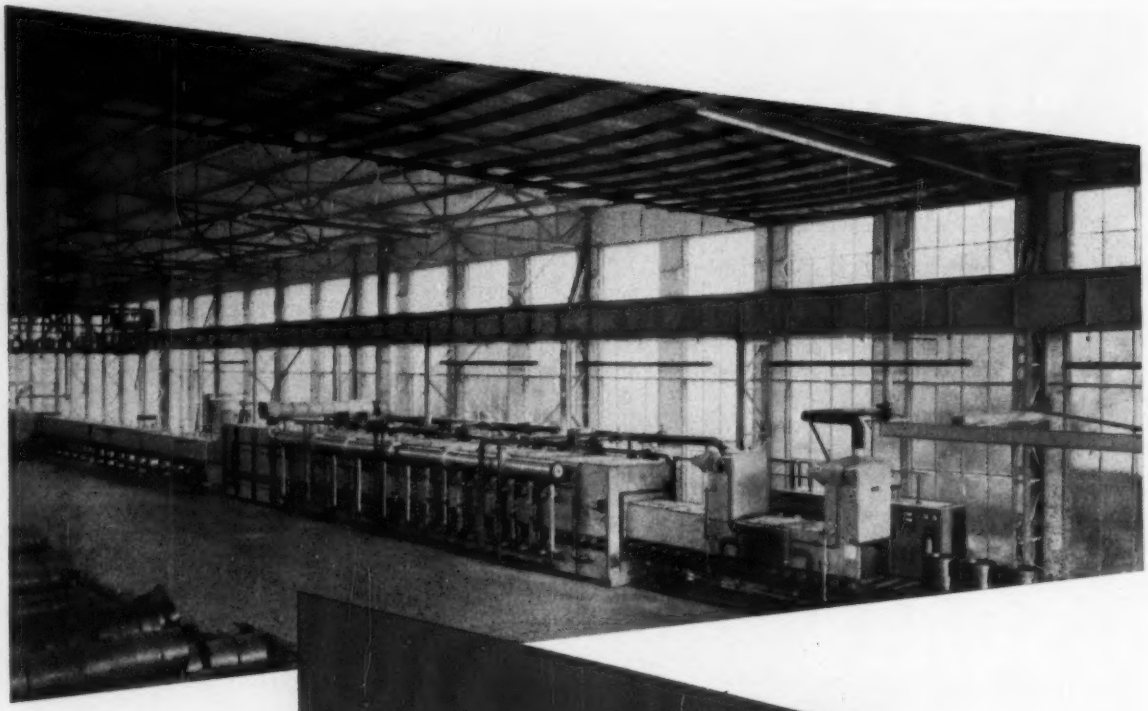

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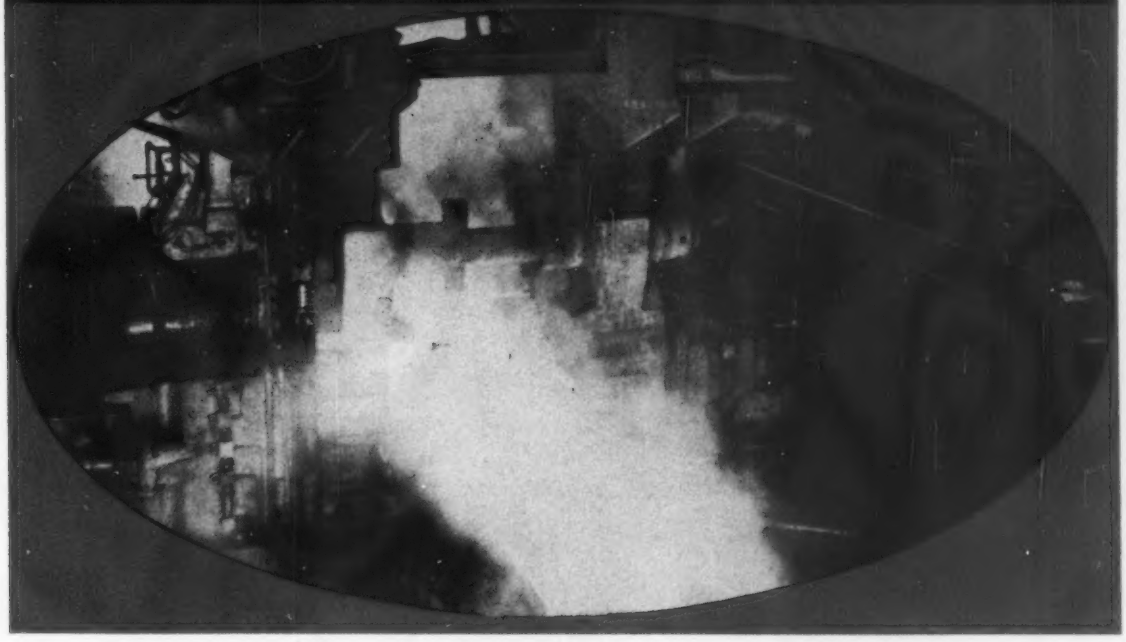

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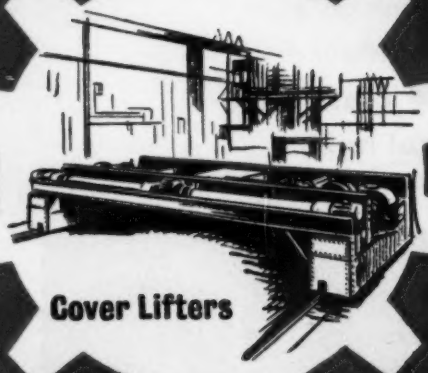
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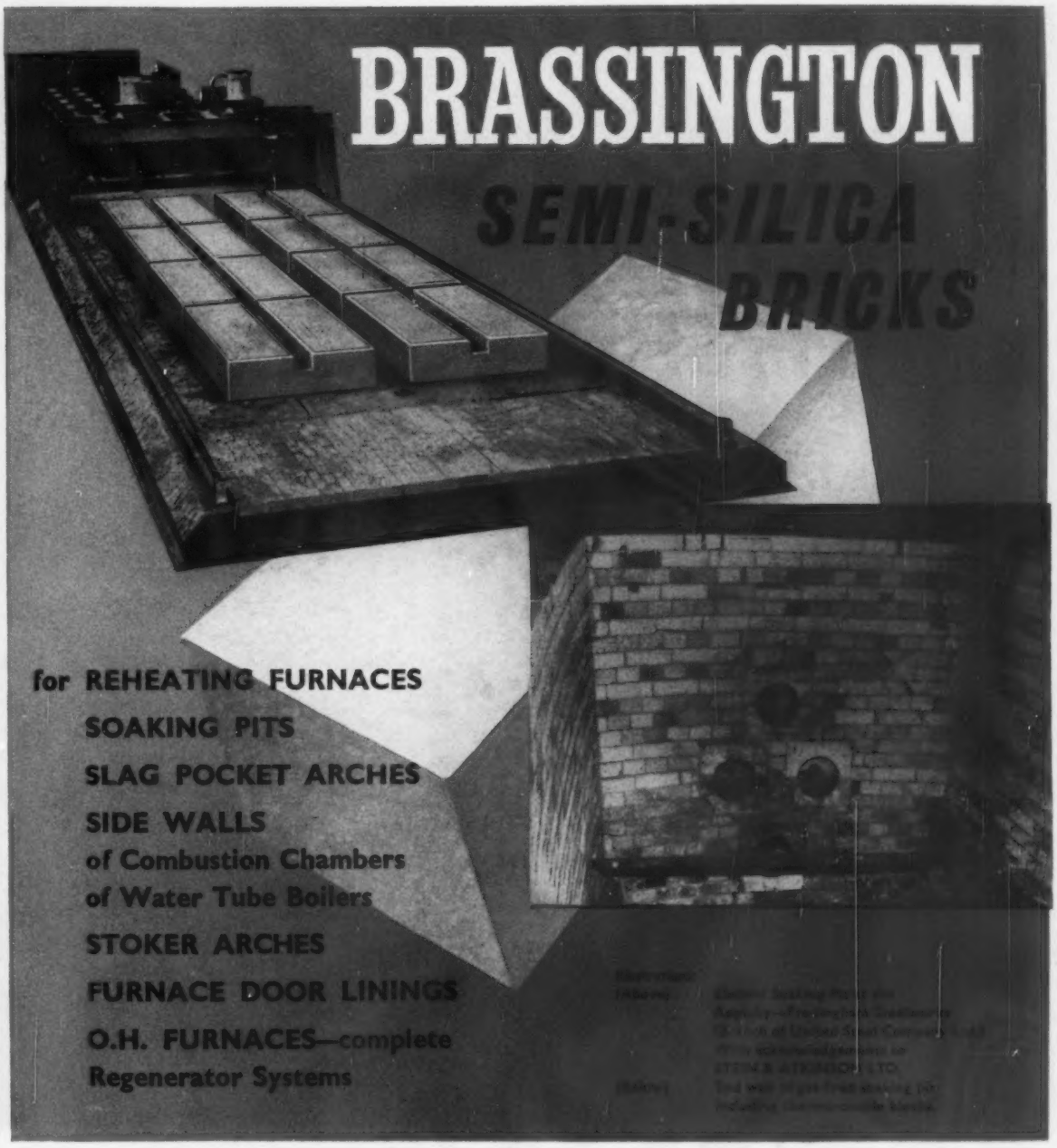

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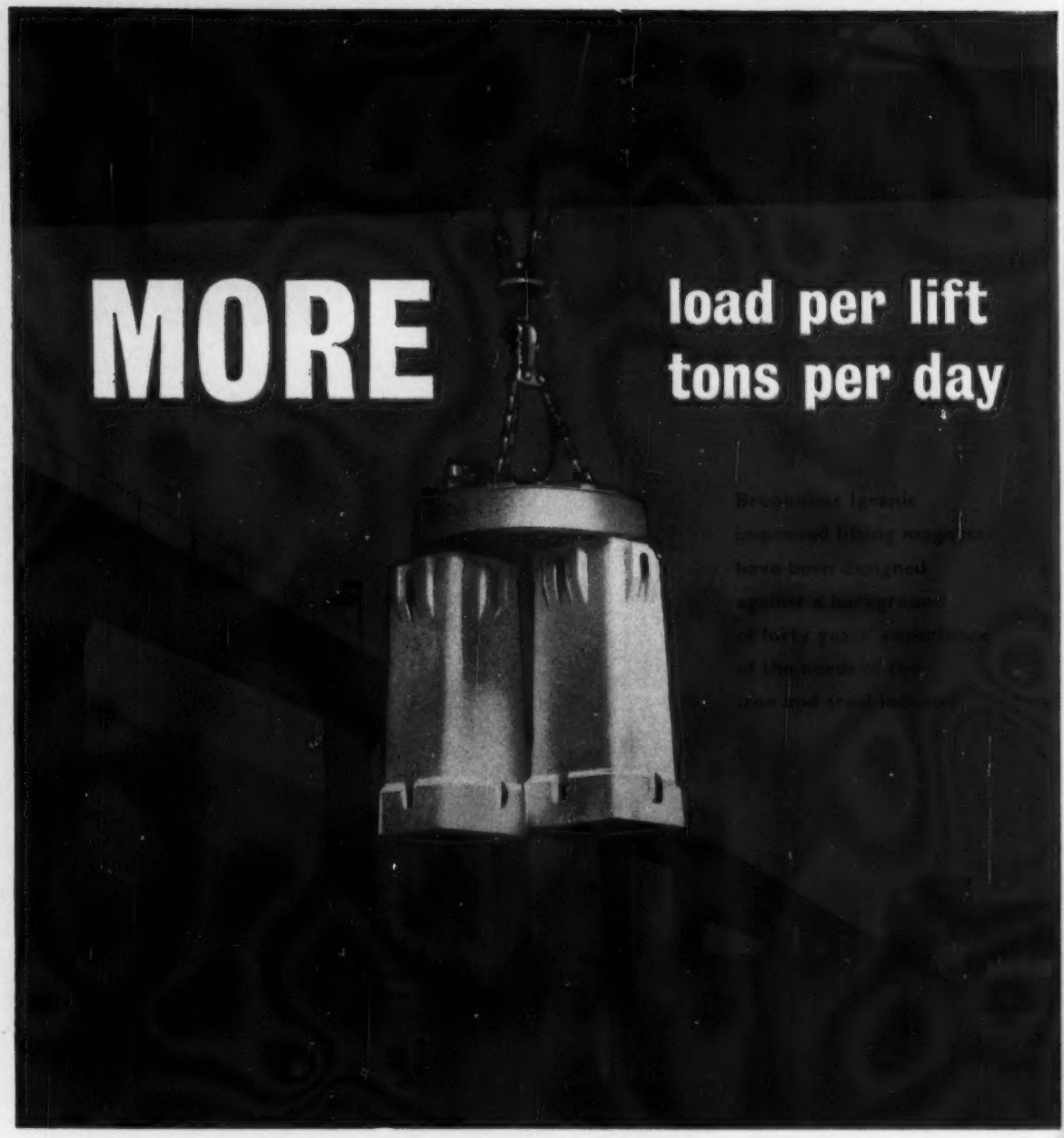

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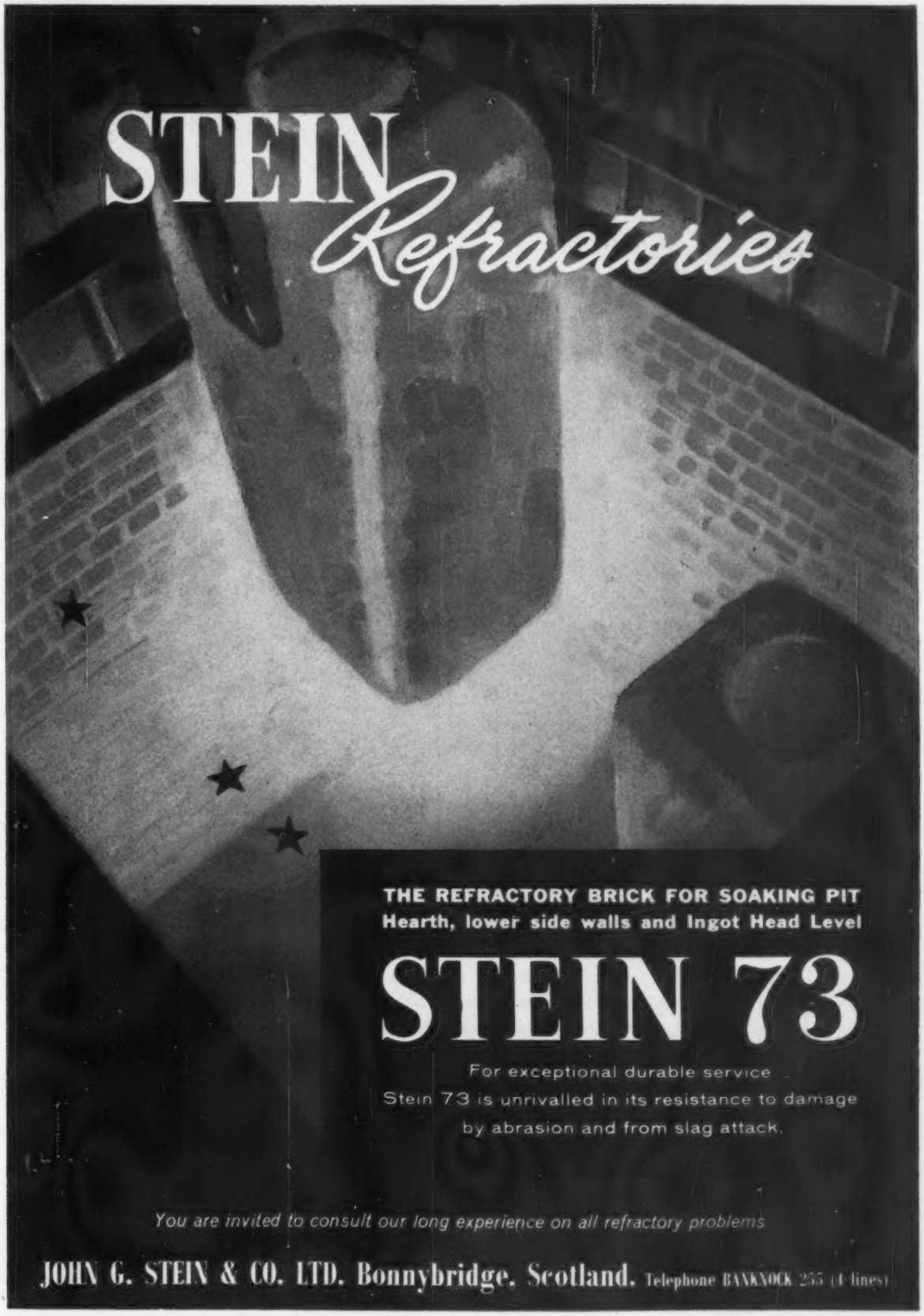
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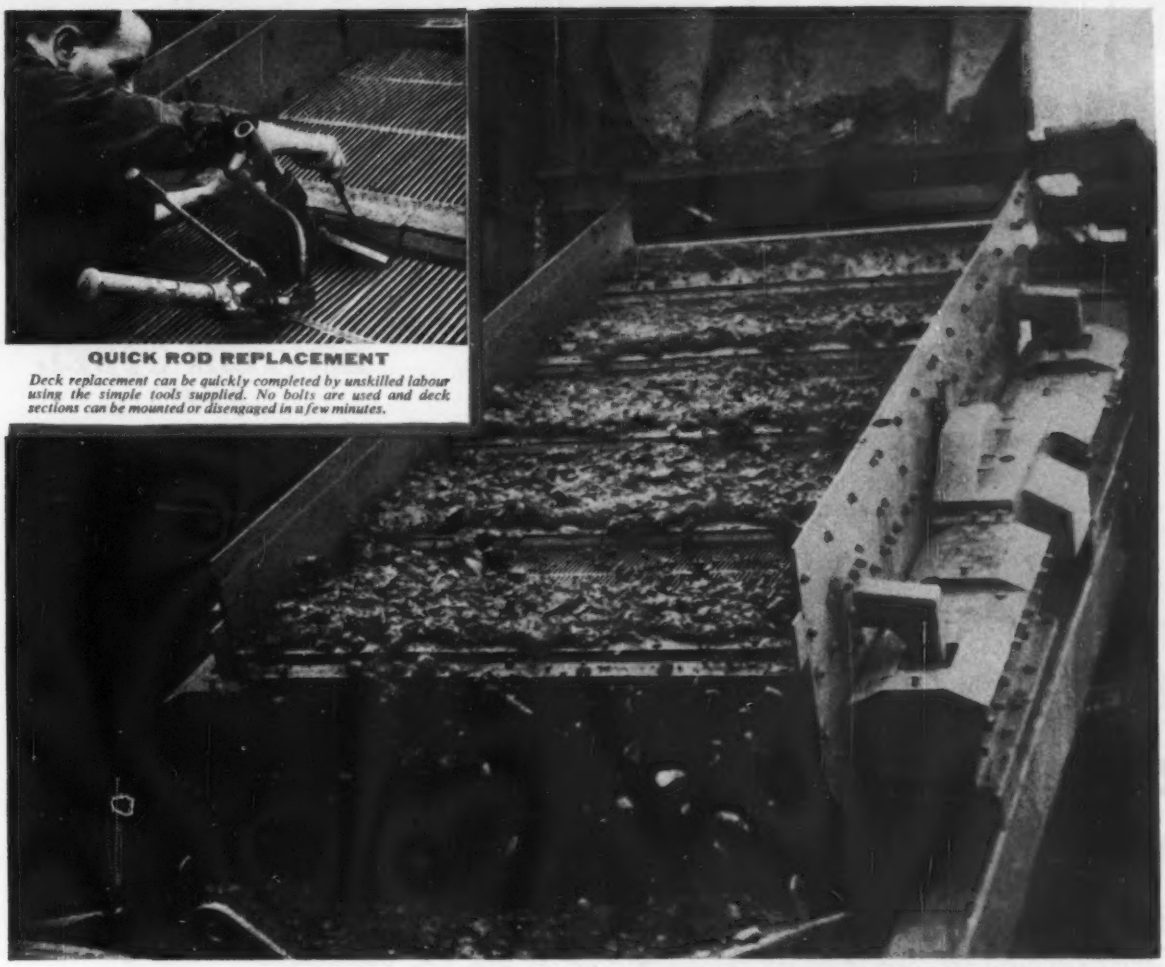

A 6′ x 12′ Ty-rock rod deck screen undergoing tests with Labrador 'B' ore at Derby Works.

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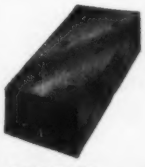
COVERED BY BRITISH PATENT No 546, 220

For over 10 years General Refractories Ltd. have manufactured steel-clad basic bricks under licence by the Heuer processes. **One of the principal features of Ferroclad is that the graded refractory material and metal casing form an integral unit by means of controlled hydraulic pressure—no air infiltration—the case fits like a glove.** It is made in four main qualities to suit requirements. Ferroclad bricks are extensively used in the roof, front and back walls, and ends of basic open hearth furnaces; in basic electric furnaces; and in copper reverberatory furnaces.

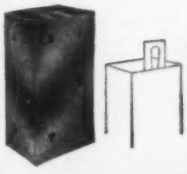
FERROCLAD 'EE' BRICKS



Divided internally by two plates placed lengthwise. This system reduces flaking and spalling to a minimum and can be applied to all Ferroclad shapes and sizes.

COVERED BY BRITISH PATENT Nos. 546, 220., 778, 047., and 778, 048

TABHANGER SUSPENSION



Bricks supplied with a special stainless steel tab co-moulded with the brick, embedded into the surface of the top face. By the use of a special tool the tab may be bent out at right angles to the top face to form a hanger.

COVERED BY BRITISH PATENT Nos. 546, 220 and 749, 491

FERROCLIP SUSPENSION

This method allows the brick to be suspended from the end. The Ferroclip hanger slot may be moulded into any roof or wall shape.

COVERED BY BRITISH PATENT Nos. 546, 220 and 600, 630

The basic process of metal-cased brick manufacture is covered by British Patent No. 546,220 and other additions, including the "Ferroclip," the "Tabhanger" and the "EE", are covered by British Patent Nos. 546,220, 600,630, 749,491, 778,047 and 778,048.

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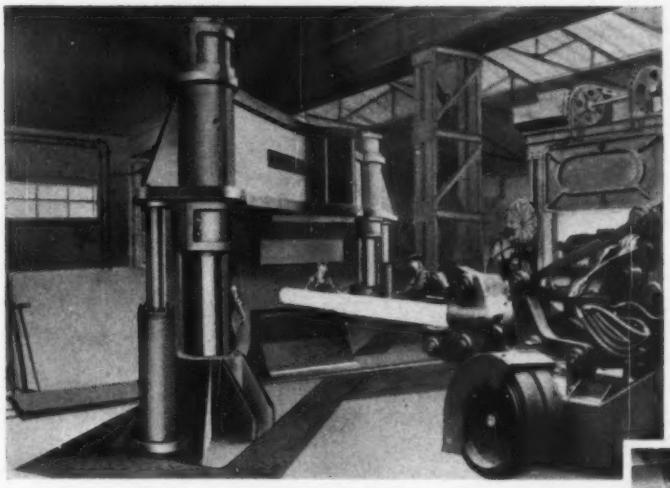

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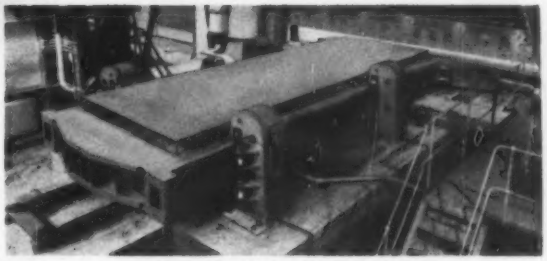

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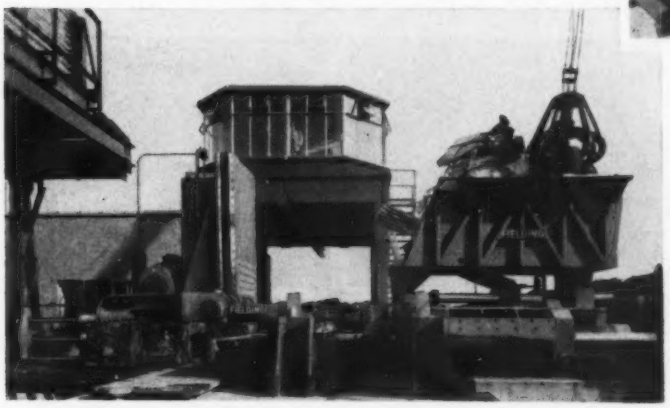

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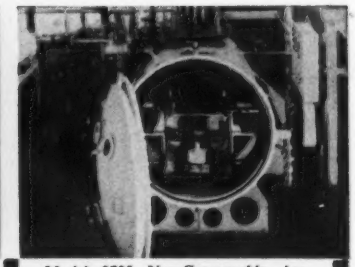

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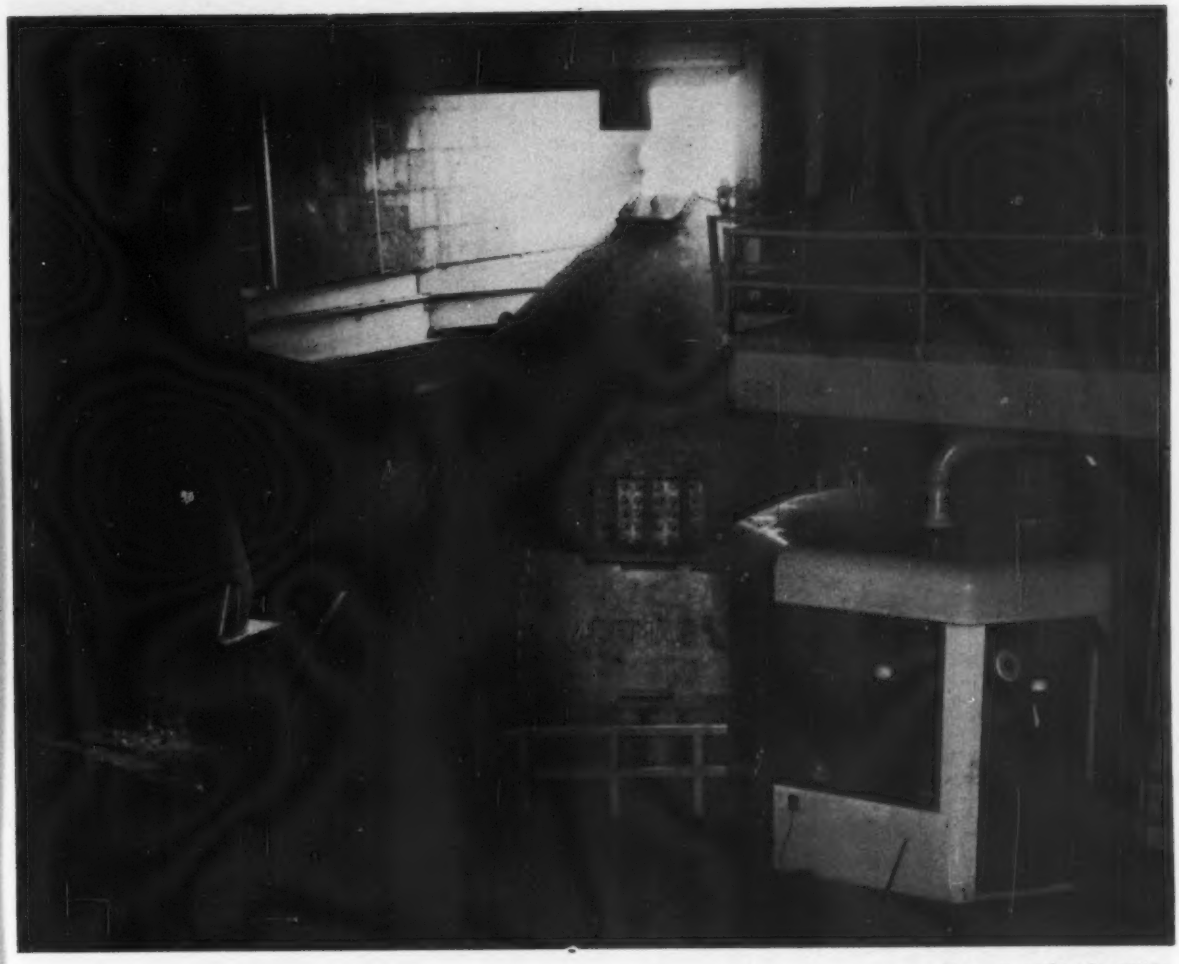

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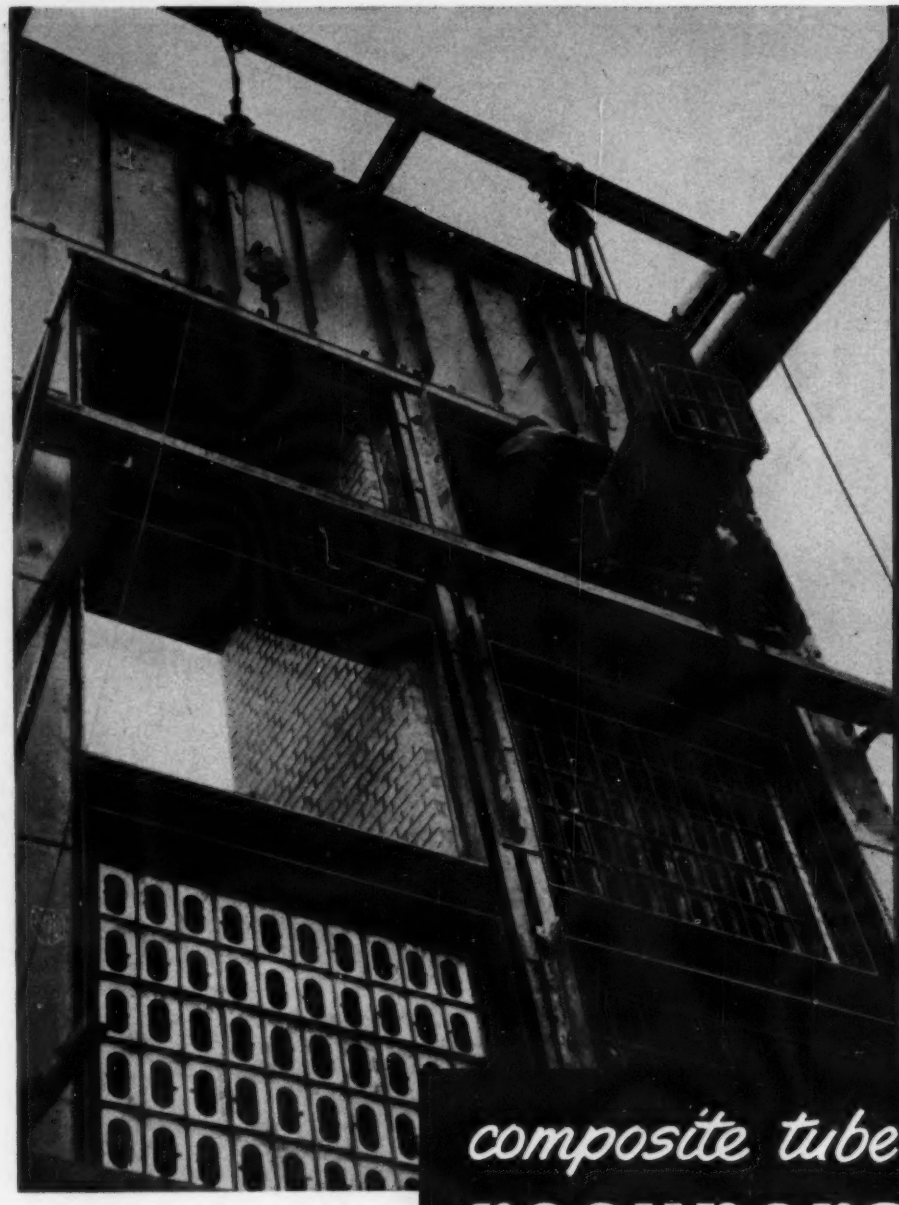

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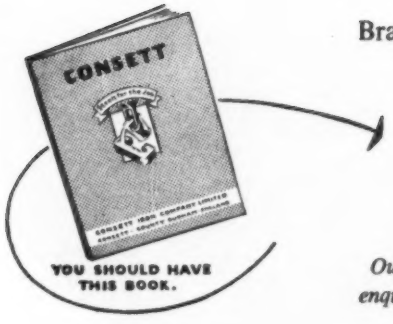

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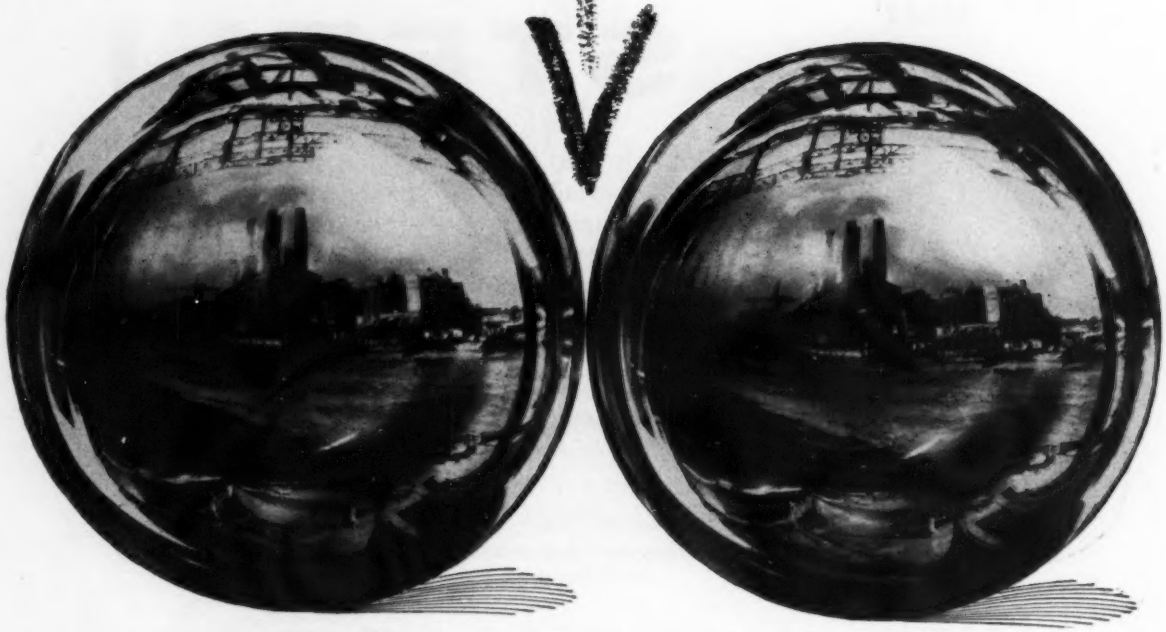

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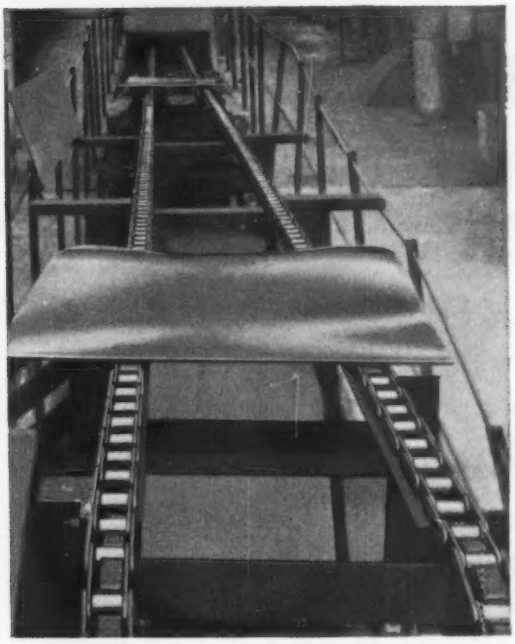

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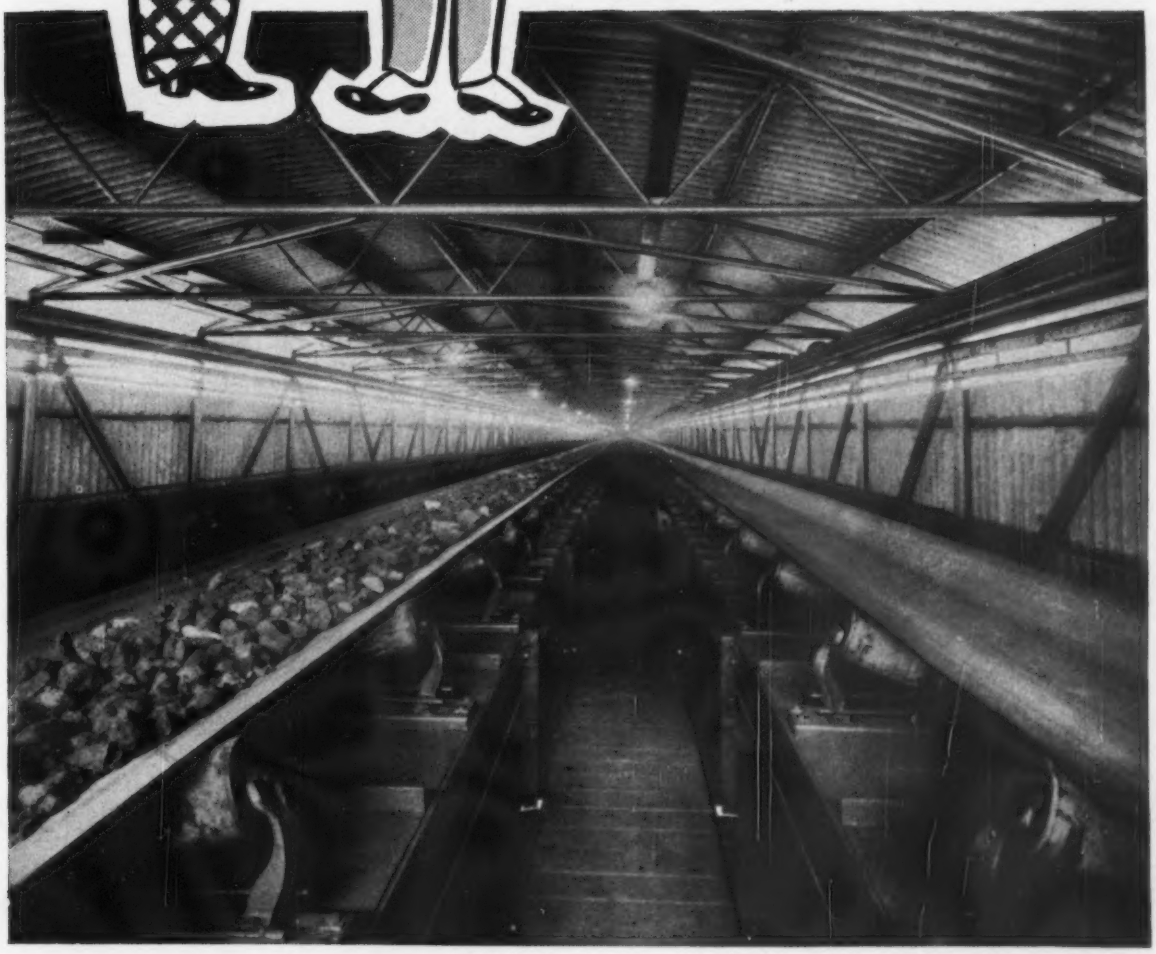

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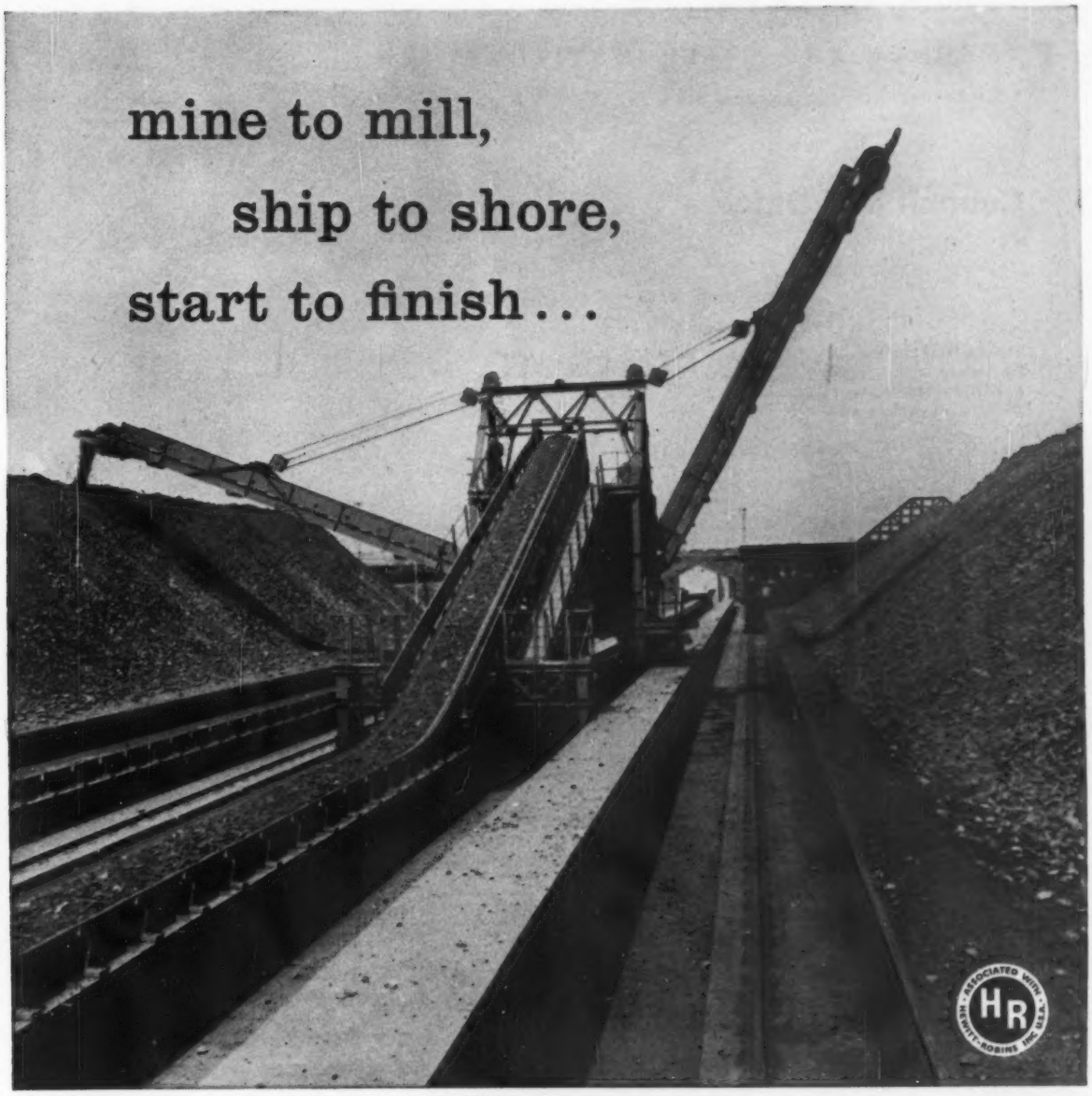

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P. M. THOMAS, D.S.O., T.D., M.A.

PATRICK MUIRHEAD THOMAS was educated at Clifton College and Corpus Christi College, Cambridge, taking an Honours degree in the Mechanical Sciences Tripos in 1935. The same year he joined The United Steel Companies as a graduate apprentice, first with Messrs Samuel Fox and later in the Central Research Department, working on mechanical properties and creep. In 1938 Mr Thomas joined Arthur Balfour and Co. Ltd, when their new high-frequency induction melting shop was just being started.

From 1939 to 1946 he saw service with the 71st (W.R.) Field Regiment, Royal Artillery (T.A.), and the 46th Divisional Staff in France, North Africa, and all countries in the Mediterranean Theatre. He rose to the rank of Lieutenant-Colonel, and was awarded the D.S.O. and the U.S. Bronze Star.

In 1946 Mr Thomas joined William Beardmore and Co. as Assistant Works Manager, becoming Joint Managing Director in 1954 and Managing Director in 1957.

Mr Thomas is a Member of Council of the British Iron and Steel Federation, a Member of Council of the British Iron and Steel Research Association and Chairman of their Mechanical Working Panel, a Vice-President of the West of Scotland Iron and Steel Institute, a member of the Executive of the Scottish Engineering Employers' Association, the Deputy Chairman, Scottish Council of the Federation of British Industries. He is also a member of the Territorial Army Association for Glasgow, Governor of the Scottish Film Council, and Chairman of the Industrial Film Panel, a member of the Executive Committee, Earl Haig Fund (Scotland), and member of the Secretary of State for Scotland's Clean Air Committee.

Mr Thomas joined The Iron and Steel Institute in 1957, and was elected to the Council in 1960.

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Production of stainless slabs at the continuous casting plant of Schoeller-Bleckmann Stahlwerke AG

B. Matuschka, Dr. mont. Ingo

SYNOPSIS

The paper outlines the experience of Schoeller–Bleckmann Stahlwerke AG with a continuous casting plant for steel based on the Rossi system, and the particular modifications introduced to satisfy their requirements.

Details are given of temperature-recording equipment and lubrication techniques; a speed-reducing gear was used in the present plant to maintain accuracy. To ensure purity of water additional filters were added to prevent deposition in the spray nozzles. Methods of ensuring slab quality are described. The cutting chamber is almost hermetically sealed owing to the large amount of smoke given off during flame powder cutting. A tilting mechanism operated by a crank drive is used to prevent stoppages. Ladle heating is by natural gas. Reciprocating moulds enable steels with poor casting qualities to be cast at very high speeds at a constant rate. High speeds are necessary particularly with Ti-stabilized steels, as well as protective atmospheres, e.g. propane and natural gas, and results with various speeds are given. Al content must be minimized: high percentage Fe–Ti is therefore used. The paper outlines mechanical modifications, e.g. a method of inserting the dummy bar into the mould, that were necessary, and gives figures of the time of each operation, with theoretically possible daily production figures and actual figures for the author's plant. Finally, comparative quality under various conditions is illustrated. 1865

INTRODUCTION

FOLLOWING CONSIDERABLE PROGRESS in the application of continuous casting since the 1930s in the field of non-ferrous and light metals, the thoughts of many steel men turned to the possibility of utilizing this process for the production of steel. In the continuous casting of steel, the principal difficulties are the higher temperature, the poorer heat conductivity, and especially the necessity of maintaining high output per operational hour. At the end of the war, continuous casting was intensified, mainly in Germany owing to Junghans and Rossi, and also in the Soviet Union and the USA.

Our earlier interest at Schoeller-Bleckmann Stahlwerke AG in the continuous casting of steel was also revived after the war. Dr Hans Bleckmann had already carried out tests in the continuous casting of steel in the 30s. The advantages of continuous casting were the main reason for recent attention to this problem. These special advantages include:

(i) Improved production as compared with static casting, as each strand has only a small top and bottom discard; there are no gits and no butt ingots. These discards amount to some 5% in static casting of small ingots from the average-sized furnace.

(ii) In continuous casting, it is possible to shear the strands accurately to a desired length, so that the crude steel required for the finished plate can be assessed. Discard is thus reduced to a minimum and the necessary high output is obtained. Figure 1 represents this schematically.

In the case of static casting, however, steelmakers are obliged to keep to the individual sizes of cast slabs which are not always accurate enough to suit the weight of the finished plate.

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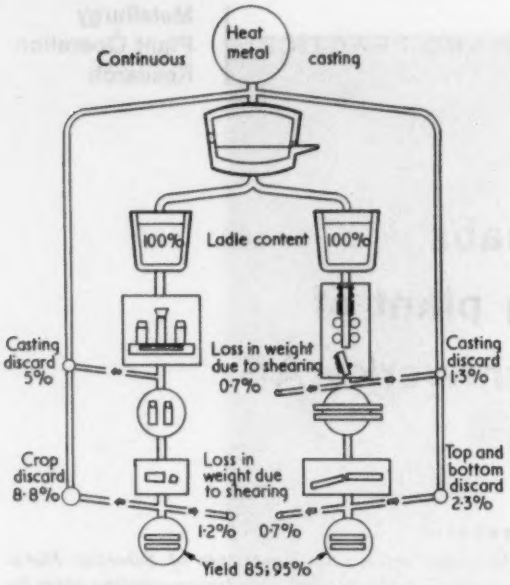
The work described was carried out by the author Bergrat D. Bernhard Matuschka, who recently retired from the post of technical director at Schoeller–Bleckmann Stahlwerke AG, in association with Ing. M. Petz, steelworks manager, and Ing. Willim, steelworks assistant.

(iii) Economy in mould costs: for purposes of comparison, the service life of a copper block mould such as we use, is at least 800 heats, which corresponds roughly to at least 10000 tons of crude steel. Mould costs in continuous casting are, therefore, about one-tenth of those in static casting.

(iv) By mechanizing the entire casting operation, a certain amount of space is saved and there is no need for a large ingot mould stockyard.

(v) At present we at Schoeller-Bleckmann Stahlwerke AG are statically casting 600 kg slabs. We are also continuously casting slabs of



1 *Comparison of static and continuous casting*

approximately the same size. Substantial economies are achieved in rolling when traditional statically cast slabs of large dimension are compared with the substantially smaller size obtained by continuous casting. Much hot working is thus eliminated.

(vi) The high degree of cleanliness of continuously cast material is a further advantage, since almost all harmful inclusions and segregations are removed and casting is carried out in a protective gas atmosphere.

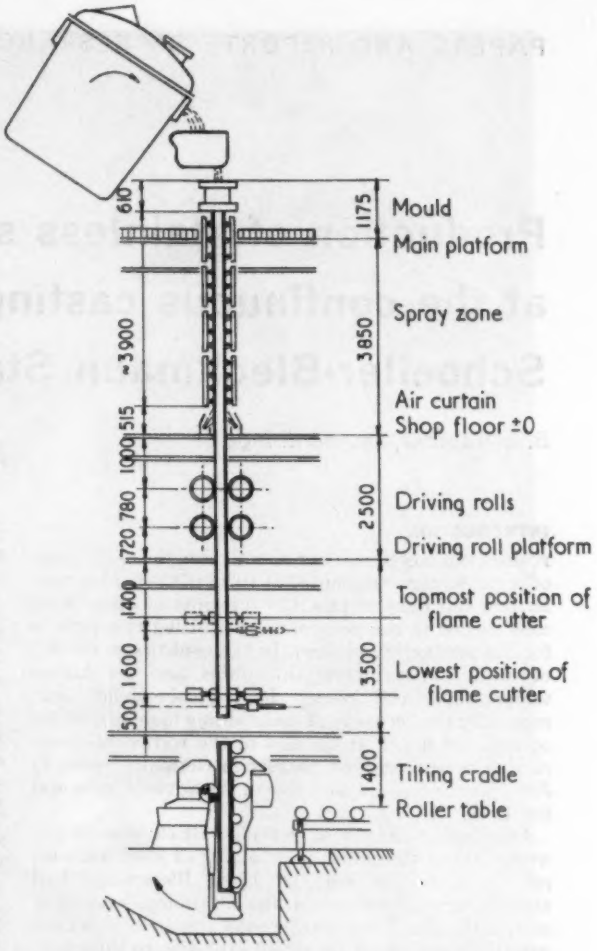
Because of these advantages, the Schoeller-Bleckmann Stahlwerke AG decided to install a continuous casting plant. The deciding factor was that it was possible with continuous casting to achieve a yield of 95%, while with static casting, the yield was only 85%. The Rossi system was chosen because it combines relatively quick casting and short casting times with good surfaces.

Figure 2 illustrates our continuous casting plant diagrammatically. Figure 3 gives a view of the casting platform, and Fig.4 shows casting in progress.

The continuous casting plant can be fed by three arc-furnaces of 8, 12, and 18 tons capacity. Heat-resisting and stainless qualities are cast. Three teapot ladles are available for casting.

DESCRIPTION OF THE CASTING PROCESS

If the continuous casting operation is to be satisfactory, it is essential to record the temperature of the metal in the furnace, at tap, with an immersion pyrometer. After finishing the heat, and adjustment to correct tapping temperature, the steel is tapped into a teapot ladle which has been preheated to about 1 100°C. The ladle is then transported to the adjoining shop. A crane lifts it on to the continuous casting machine and places it on the tilting mechanism. The time required for this operation is about 8–10 min.

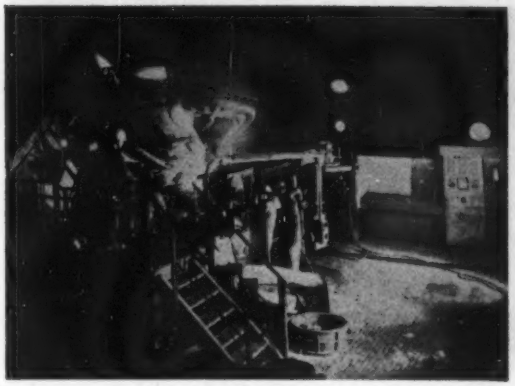


2 *Diagram of continuous casting plant*

As soon as the ladle reaches the continuous casting machine, the first immersion temperature measurement is made. This figure is then registered and recorded. Although these temperature measurements in the ladle are conscientiously made, certain variations do occur, especially with titanium-stabilized stainless qualities. In order to record the course of the temperature as accurately as possible, the immersion temperature in the ladle is taken at intervals and charted on a diagram. This will be dealt with in more detail later in the paper.

When the temperature fixed for the beginning of casting is reached, the ladle-heating apparatus is switched on. By heating the ladle during casting, it is possible to maintain the temperature almost constant from the beginning to the end of casting. The decrease in temperature at the end of casting is not more than about 10°C.

As a teapot ladle is used, the ladle spout is cleared directly before casting by a short blast of oxygen. Tilting now begins and the first part of the steel, which is contaminated with slag, runs from the ladle into a separate container. When the steel is free of slag, the



3 *View of the casting platform*

4 *Casting of X10* Cr–Ni–Ti 18–9

metal is poured into a tundish, which has also been preheated to about 1 100–1 200°C. At the bottom of the tundish, there are two zirconium silicate outlets, which ensure maximum uniformity of flow into the slab mould. The first steel to leave the tundish tends to splash and flow unevenly as a meniscus has not yet formed in the tundish and it has, therefore, to be channelled off into a special separate container. This prevents splashing in the mould. When the steel meniscus is clear and smooth, the channel is swung aside and casting begins.

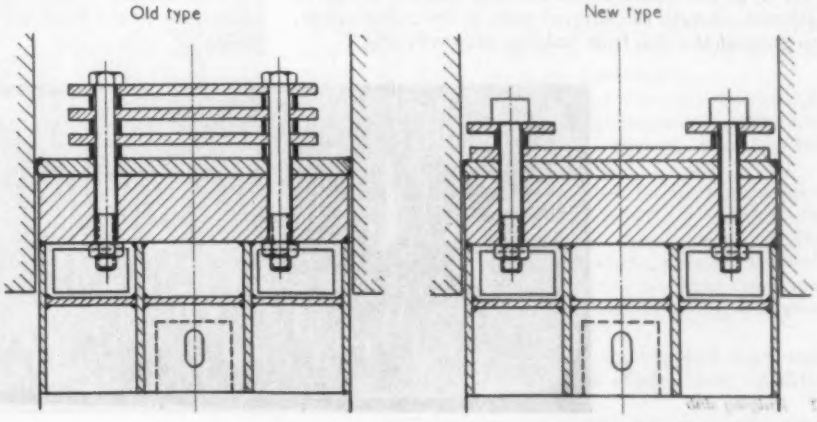
A few words may be said here about the type of connexion between the molten strand and the dummy bar (*see* Fig.5). The hot strand is coupled to the dummy bar by bolts with plates firmly fixed to them. Originally there were two bolts and three connecting plates. The descending stream of metal is diverted by the top plate. By this means, the mould was twice scoured to a depth of some millimetres. These defects could be filled up again by welding, but this is a very complex process as the copper mould must be heated before welding to about 700–800°C to effect union of the surface weld with the parent metal.

These stoppages and other defects made it necessary for us to alter the head of the dummy bar several times. Among other things, difficulties were caused by excessive heating of the connecting bolts.

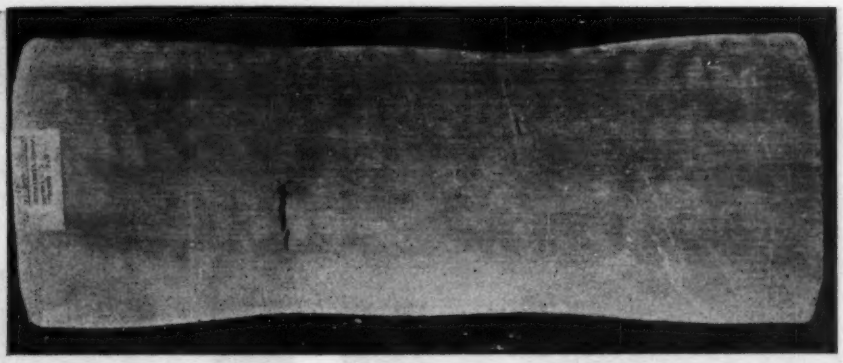
When the first steel enters the mould, the lubrication is switched on. Pumps feed rape seed oil to the upper rim of the mould, where it is uniformly distributed over the mould wall down to the surface of the molten metal. Lubrication must be as restricted as possible, to prevent blow holes and carburization. Carburization due to excess oil was evident with extra low carbon steels.

In order to ensure greater accuracy in the amount of oil supplied, during casting, an infinitely variable PIV speed-reducing gear is installed between the engine and the pumps. Tests with rape oil gave poor results, but more promising tests are now being undertaken with mineral oil.

The casting plant used softened water at 8 atm abs gauge mains pressure for mould and secondary cooling and for cooling the machine. The pressure required for the four spray zones and for the mould is directly adjusted at the casting installation.



5 *Slab dummy bar*



6 *Defects due to incorrect arrangement of the fan sprays*

It is especially important that the water should be absolutely pure. For this reason, we found it necessary to install further filters, in addition to the filters in the main supply pipe, close to the spray zones, to prevent depositions in the nozzles. Also, the spray zone pipes are made of stainless steel.

A system of support rolls and several hundred freely movable spray nozzles is suspended underneath the mould. The function of the support rolls is to prevent the slabs from bulging. To obtain good slabs, which should be as plane-parallel and as free from cracks as possible, it is essential to have a definite arrangement of the spray nozzles. At our own plant, the nozzles project fan-shaped sprays with a spray angle of 80–95°. These nozzles are connected to three pipes opposite each wide face of the slab and to a single pipe opposite each narrow face. As the jets at the outer surface of the fan spray diverge sharply from a right angle in relation to the face of the slab, intensity of cooling is not entirely uniform over the entire width of the fan. For this reason, the fan sprays are allowed to overlap each other by a few millimetres on the wide face. In this way, temperature distribution over the entire wide face, except for the edges, is kept uniform. If, on the other hand, cooling sprays are adjusted so that they adjoin each other without overlap, two bright streaks appear on the slab. The slab is concave at these points and is prone to develop internal cracks there (Fig.6).

With oxyacetylene cutting, it is desirable that the edges be kept as hot as possible. If cooling is such that the edges are of roughly the same temperature (about 800°C) as the remainder of the slab surface, it will be difficult, despite the support rolls in the roller apron, to prevent the slab from bulging outwards (Fig.7).

When casting austenitic stainless slabs, a secondary cooling rate of approximately 3 litres of water per kg of steel was found to be appropriate. In the case of pure-chromium steels, which are considerably more sensitive to internal cracks, we attempted, on the basis of other experience (mainly Russian) to throttle the secondary cooling as much as possible. However, whereas Russian experience showed that with qualities prone to cracking, only 1–1·5 litre/kg steel are required for cooling, we were unable to reach these low figures with our own installation because of the short mould and the relatively high withdrawal speed of 1 m/min. Despite this, a structure free from cracks was obtained.

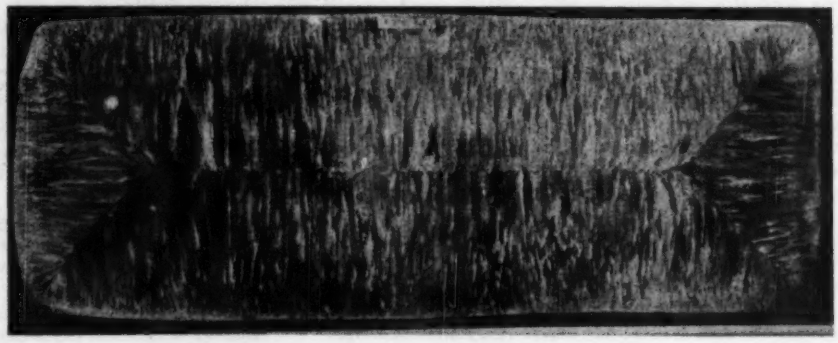
If the withdrawal speed is 0·8–1·0 m/min and the amount of cooling water is reduced to less than 2 litre/kg steel, marked bulging of the slab will occur below the roller apron. This is because cooling is insufficient to complete solidification within the roller apron.

For complete cooling, 20 m^3 of water per ton of steel are required. As the water is recirculated, the above amount cannot be recorded as effective consumption; the amount to be replaced is actually a circulation loss of about 5%.

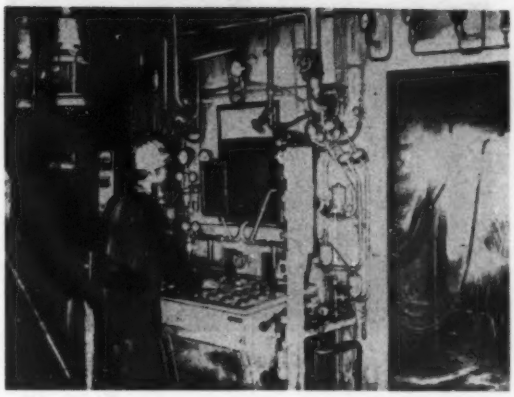
It should be mentioned here that the power consumption of the entire continuous casting installation is about 8 kWh/ton of steel.

The roller apron is suspended in a closed chamber. A curtain of air prevents the water from flowing along the slab on to or below the driving rolls.

After leaving the roller apron, the slab enters two pairs of driving rolls. The two rear rolls are fixed, while those at the front are pressed by springs against the slab.



7 *Bulging slab*

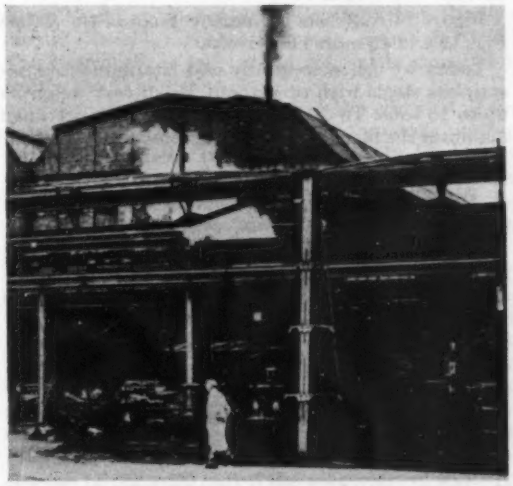


8 *View of the cutting platform*

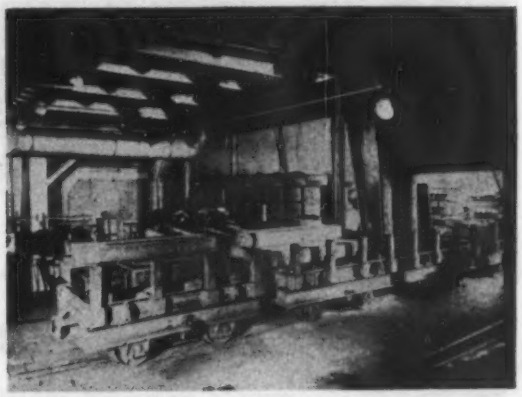
The installation is built in such a way that it is possible to cast both cross-sections of 80 mm square and slabs weighing up to 700 kg/linear m. It has, therefore, been necessary to arrange the springs so that the small pressures needed for small cross-sections can be maintained with the same reliability as the large pressures required for slabs.

Below the driving rolls, the slab is cut to the desired length by flame powder cutters (Fig.8). The slabs are cut by two burners operating simultaneously. Since it is almost entirely stainless qualities that are cast, the use of cutting powder is essential. About 50–70 s are required for a cut. On the plant, slabs 1300–2250 mm long can be cut. Any further reduction in length can, if necessary, be carried out away from the installation. With the usual withdrawal speeds, therefore, there is ample time for cutting even with the shortest slab length.

During flame powder cutting, a large amount of smoke is given off (Fig.9). The removal of this smoke by suction presented many difficult problems and finally the cutting chamber was almost hermetically sealed. Figure 9 gives an impression of the amount of smoke developed.



9 *Smoke developed during powder cutting*



10 *Slab transport device*

The following are necessary for a single cut:

oxygen	2·50 m³
dissolved acetylene gas	0·15 m³
nitrogen	0·10 m³
cutting powder	1·00 kg.

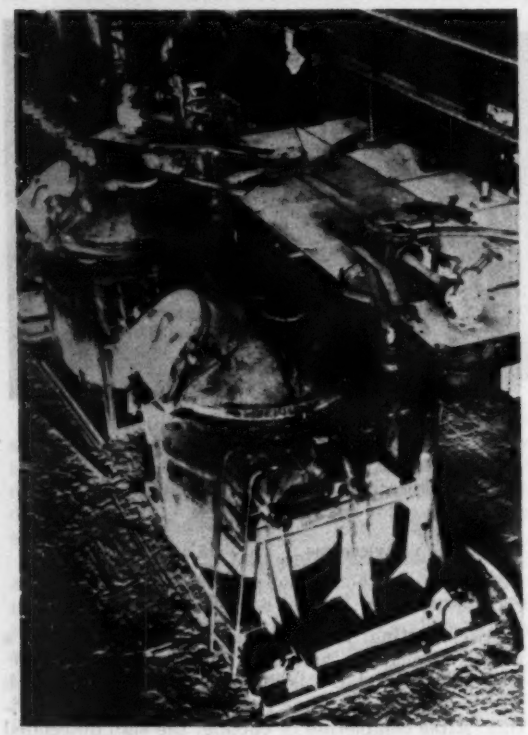
After cutting, the slabs are lowered further by a tilting mechanism and then laid on a roller table. Originally, the slab was directed into a cradle which was lowered at the same rate as the slab during cutting. After completion of cutting, the slab descended more rapidly. The tilting cradle containing the cut slab was then tilted through 90° and the slab was pushed out on to the roller table. This arrangement was too apt to cause stoppages and was replaced. In the new tilting mechanism, the cut slabs are lowered and held by two spring rolls pressing against each other. The former tilting mechanism used a chain drive, but the new one is operated by a crank drive. An oil engine is used to turn the pinch rolls which lower and deliver the slab on to the roller table. This new and very sturdy unit has so far given a magnificent performance without any stoppages. From the tilting mechanism, the slabs travel on the roller table to a lift which conveys them to the shop floor where they are placed on bogies (Fig.10). The slabs are subsequently taken to the ingot stockyard.

To operate the continuous casting plant successfully on a three-shift basis, it is essential to have a suitable ladle-heating system (Fig.11). Near the plant are two ladle-heating units fired by natural gas. One of these heats the ladle in preparation for a cast, and the other is used for drying out newly lined ladles.

The first casting on our plant was carried out at the end of December 1957; to train the operating crew and eliminate teething troubles, casting was at first restricted to unalloyed qualities.

The production of special steel began in September 1958 with the casting of stainless slabs. Right from the start it was decided to cast mainly high quality, especially austenitic stainless steels, because it is with these special qualities in particular that improved production, as compared with static casting, is of great importance.

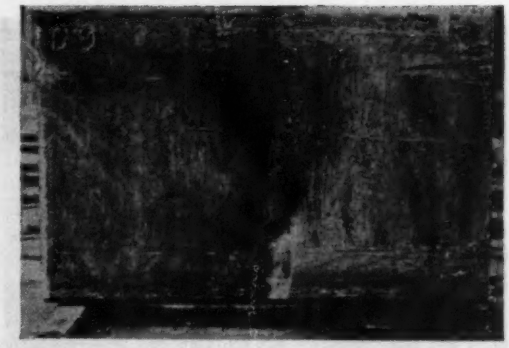
Since no difficulties were anticipated with non-stabilized austenitic stainless steels, these qualities



11 *Ladle heating*

were the first to be cast. No great difficulties were actually encountered in the casting of these types. From November 1958 onward, titanium-stabilized stainless qualities were introduced into the casting programme. It is generally known that titanium-stabilized steels are very difficult to cast successfully. In an effort to improve the castability of these steels, we attempted to prevent oxidation as far as possible during pouring by casting in a protective atmosphere. We originally used propane as a protective gas but we now use natural gas. Despite this use of protective atmospheres, however, we did not succeed in obtaining a good surface unless casting was carried out at a very high rate.

A reciprocating mould is also included in our plant. We believe that successful casting of titanium-stabilized steels is only possible with this type of



13 *Surface of a titanium-stabilized slab, continuously cast at a speed of 0·9 m/min*

mould. At this juncture, the extreme importance of reciprocating moulds in continuous casting should be stressed. They enable steels with poor casting properties to be cast at a very high speed. It should not, however, be forgotten that the construction of the installation must be as rigid as possible, so that no vibration in the plant can be caused by reciprocating moulds.

Figures 12 and 13 compare the surface finish of titanium-stabilized C10 Cr–Ni–Ti 18–9 steel cast at different speeds.

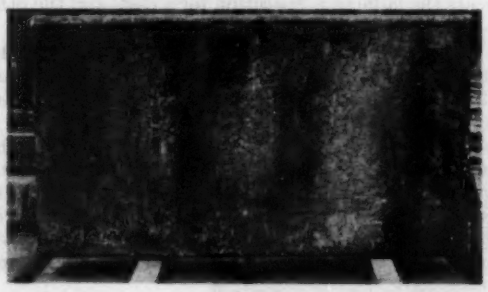
According to our experience the lowest speed at which stabilized slabs can be continuously cast is about 0·3–0·4 m/min. Good surface properties are attained with casting speeds of 0·8–1·0 m/min. Surface finish of the slab will suffer if the speed falls below 0·6 m/min.

As can be seen from Fig.12, with a casting speed of 0·3 m/min, surface finish is poor. As a result of cold shuts, the interior of this slab did not meet the specification.

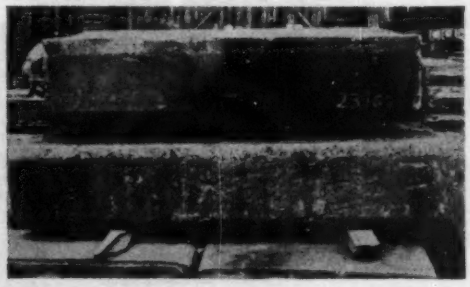
Figure 13 shows the surface finish of the same titanium-stabilized quality cast at a speed of 0·9 m/min. The condition of this surface is comparable to that of a statically cast slab of the same quality. The interior of the slab was sound.

Figure 14 contrasts the narrow faces of the slabs in Figs.12 and 13 more effectively.

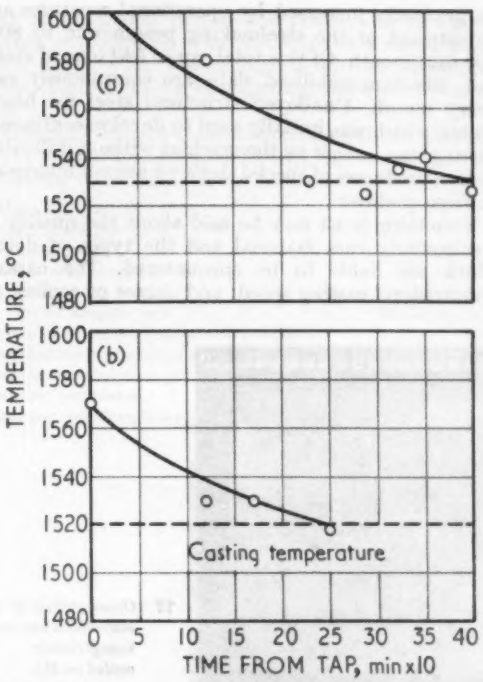
Today we can successfully cast titanium-stabilized, stainless steels with or without Mo in cast weights of up to 18 tons. To do this, however, it is important to maintain the most stable casting temperature possible



12 *Surface of a titanium-stabilized slab, continuously cast at a speed of 0·3 m/min*



14 *Narrow sides of two titanium-stabilized slabs, continuously cast at different speeds*



15 *Temperature curve for X10* Cr–Ni–Ti 18–9 *steel with* (a) 38–42%FeTi, *and* (b) 70–80%FeTi

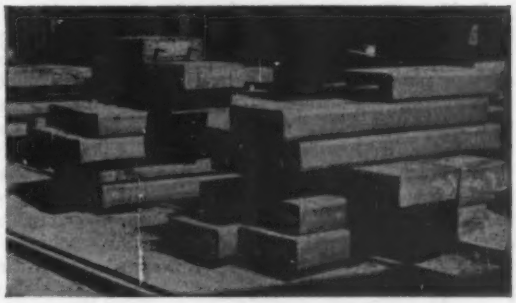
throughout the entire cast and to keep the Al content to a minimum.

If 38–42% ferro-titanium is used, it is hardly possible to fulfil these requirements, because on the one hand uniformity of temperature throughout the bath is very greatly disturbed owing to the addition of a large amount of titanium, and on the other hand because this ferro-alloy includes large percentages of Al, which result in a content of 0·10–0·12%Al in the final analysis. A very poor flow, therefore, inevitably results.

In the production of titanium-stabilized stainless steels, therefore, we use high percentage ferro-titanium (about 70–80%) containing only about 0·10%Al. Simultaneously, a low carbon content is aimed at to reduce the Ti additions.

In Fig.15*a* it can be seen that the addition of low percentage FeTi (38–42%) does not produce uniform temperature of the steel in the ladle. In Fig.15*b* the temperature is seen to be more or less uniform. The harmonious co-ordination of all these factors makes possible the successful continuous casting of titanium-stabilized steel.

Figure 16 shows some titanium-stabilized slabs which have been produced by continuous casting. Titanium-stabilized continuously cast slabs are cut by machining after casting at our plant, in the same way as statically cast slabs of the same quality. To achieve the best possible output, the surfaces have to be as plane-parallel as possible. We have already mentioned the influence of uniform cooling on the slab surface. It should also be stated that good plane-parallel properties can be obtained only if the proportion of water per kg of cast steel is maintained within narrow limits. If



16 *Titanium-stabilized continuously cast slabs*

cooling is too intense the wide faces become concave, and if it is inadequate they bulge outwards. A prerequisite of the correct adjustment of secondary cooling is that the rate of casting should as far as possible be constant, and with titanium-stabilized qualities this is only possible if such controlling measures are taken.

Since in the case of slabs the casting output is very high (35 tons/h), the actual casting time alone is only a minor consideration when assessing the performance of the continuous casting plant as a whole. To obtain the highest production possible, the tapping temperature of the furnace must be as accurately maintained as possible and must never be too low. The period between tapping and the beginning of casting should be as short as possible. This can be successfully achieved with non-stabilized steel, but with titanium-stabilized steels, high percentage FeTi must be used.

Another factor of decisive importance in attaining high output is the time required after casting to prepare the plant for the next cast. To gain time, the dummy bar for the subsequent slab is now inserted in the mould from the top, and not from below as previously, before the end of the preceding slab has left the mould. Owing to the slow crane with which we have to work, we require about 50 min for preparation at present.

The following shows how the time is divided in continuous casting:

preparation time	1 h
transportation of ladle from furnace to plant	10 min
temperature adjustment on the plant	30 min
casting time	30 min
	2 h 10 min

The theoretical number of casts in 24 h is, therefore, 24:2·17=11·1 casts. In fact, however, only 70% of the heats available from three furnaces are tapped at times when they can be cast on the continuous casting plant. The actual result is therefore:

11·1×0·7=7·8 casts every 24 h

On the condition that three furnaces were available with capacities of 8, 12, and 18 tons respectively, the result would be an average heat weight of

$$\frac{8+12+18 \text{ tons}}{3} = 12{\cdot}7 \text{ tons.}$$

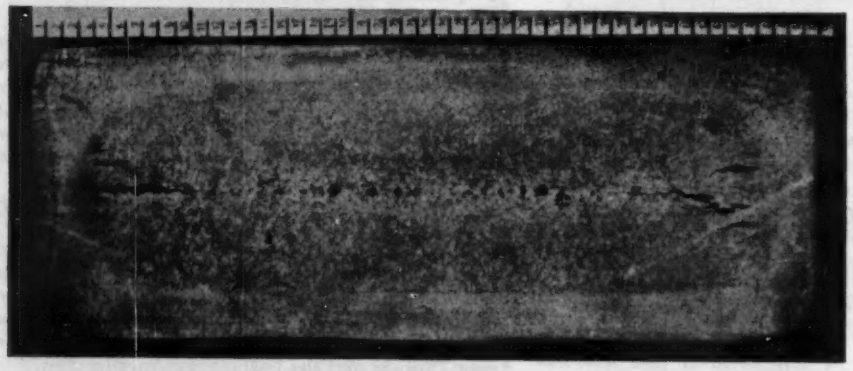
The possible daily production is therefore

12·7×7·8=99·06, i.e. about 100 tons.

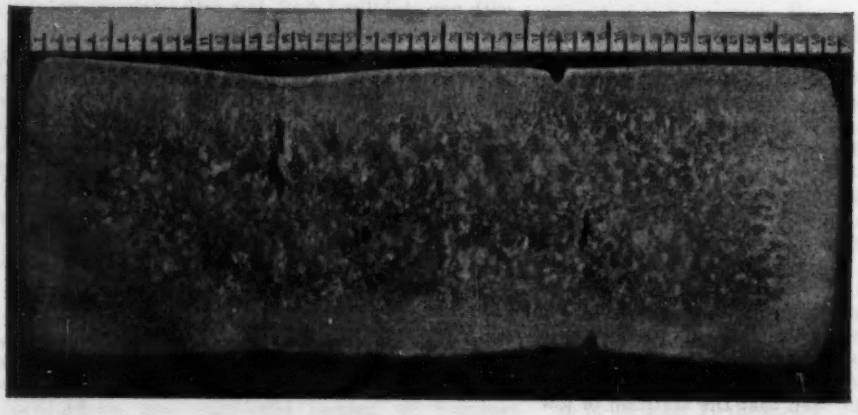
In 25 working days, therefore, the plant could have a maximum output of 2500 tons but only if all three furnaces were continuously feeding the continuous casting plant, and provided that 70% of the heats tapped could be absorbed by the plant. This calculation is valid, however, only for the production of the usual unalloyed qualities in current production. In plants producing special steels, it is often the case that only a portion of the qualities produced are intended for continuous casting, and have to be produced in the sizes available from the continuous casting machine.

In our own mixed programme of special steels, the production of continuously cast, stainless slabs can be gradually increased by operational measures and adjustment of the steelmaking programme to 800–900 tons/month. Of this total, up to 540 tons of stainless, titanium-stabilized slabs are continuously cast every month. Unalloyed structural steel for heavy plates, which was initially used to develop continuous casting, can be cast on the machine without difficulty, but, as producers of special steels we are not interested in these qualities.

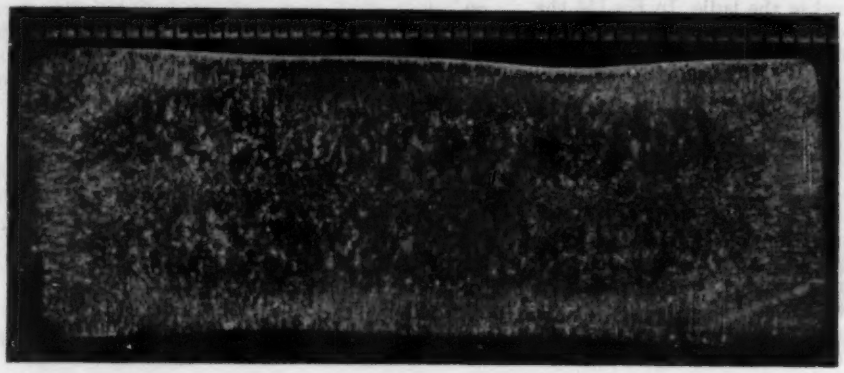
Something must now be said about the quality of continuously cast material and the types of defect which are liable to be encountered. The casting temperature, casting speed, and degree of cooling all



17 *Cross-section of a slab which has been insufficiently cooled on the narrow face*



18 *Cross-section of a slab with overcooling of the narrow face*



19 *Cross-section of a slab of C22 steel*

play an important part in the production of a good quality cross-section. Our first tests on a slab section were made with low-carbon unalloyed structural steels. Figures 17–24 characterize the defects occurring.

Figure 17 shows a cross-section of a slab of C22 steel, the cooling of which was defective.

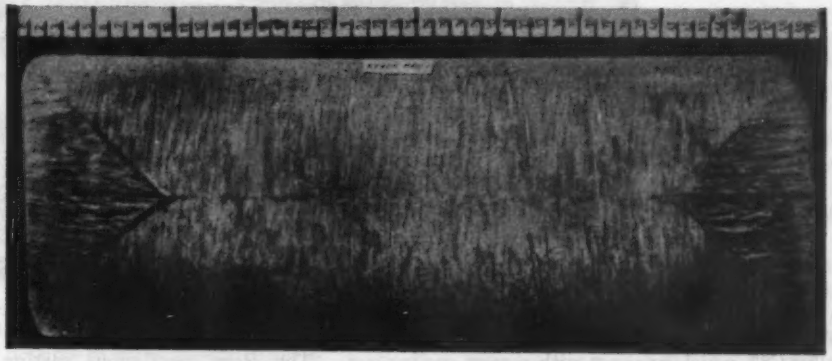
Casting conditions were as follows:

Heat 122062 C22	
casting temperature	1565°C
casting speed	0·8 m/min
water consumption	
(*a*) on wide face	1784 litre/min
(*b*) on narrow face	262 litre/min
ratio of water consumed on wide face to that consumed on narrow face	6·8
water consumption per kg/steel	3·6 l
weight per metre	720·0 kg
narrow face insufficiently cooled	

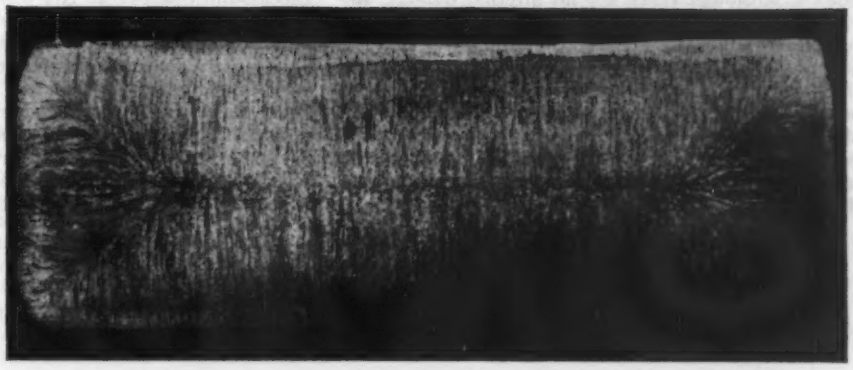
Figure 18 shows the same quality C22, with casting conditions as follows:

Heat 122080 C22	
casting temperature	1560°C
casting speed	0·8 m/min
water consumption	
(*a*) on wide face	1562 litre/min
(*b*) on narrow face	400 litre/min
ratio of water consumed on wide face to that consumed on narrow face	3·9
water consumption per kg/steel	3·6 l
weight per metre	684·0 kg
overcooling on the narrow face	

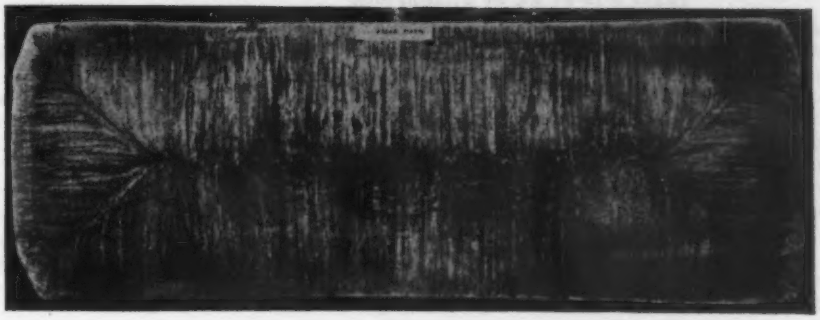
It will be seen from the comparison that the narrow face was in the first place insufficiently cooled and in the second, overcooled.



20 *Cross-section of a slab of X5* Cr–Ni 18–9 *stainless steel (primary structure)*

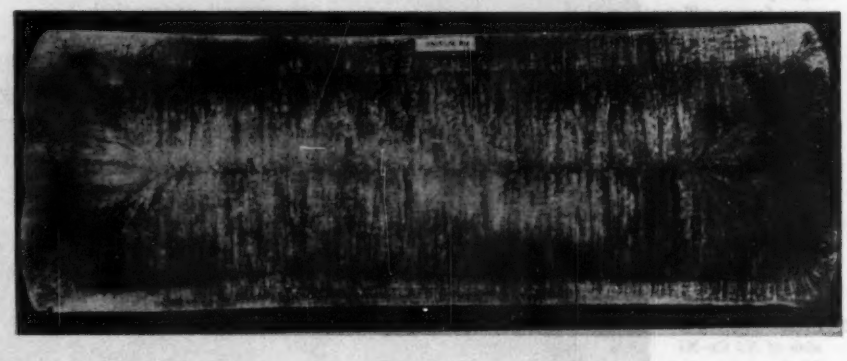


21 *Cross-section of a slab of X10* Cr–Ni–Ti 18–9 *stainless, Ti-stabilized steel (primary structure)*



22 *Cross-section of a slab of X10* Cr–Ni–Mo–Ti 18–10 *stainless titanium-stabilized steel (primary structure)*

23 *Cross-section of a slab of X12* Cr–13 *steel (primary structure)*



24 *Cross-section of a slab of X15* Cr–Ni–Si 20–12 *heat-resisting quality (primary structure)*

Figure 19 shows a cross-section of a slab, of the same quality C22, which was cast with correct cooling conditions. Although there are no internal defects, the cooling of the wide face cannot yet be said to be completely adequate. Local contraction shows that the fan sprays were still not quite correctly adjusted. From the point of view of quality, slabs of this category can be readily processed. When we adopted the production of stainless steels, special attention was devoted to the fan sprays. Figures 20–24 illustrate good-quality slab cross-sections of different stainless and heat-resisting steels.

CONCLUSION

The Rossi continuous casting plant at Schoeller-Bleckmann Stahlwerke AG was built mainly for the production of stainless slabs. As can be seen from the illustrations, the casting process must be developed individually for each steel quality. In the present state of technical development, the Schoeller-Bleckmann plant is capable of producing a very wide range of qualities. We believe that today, continuous casting has made sufficient progress for it to be regarded as fully operational. The process must, however, be adapted to the individual qualities of steel to be cast.

The morphology of martensite

P. M. Kelly, B.A., Ph.D., and J. Nutting, M.A., B.Sc., Ph.D.

SYNOPSIS

The thin foil technique for examining metals by transmission electron microscopy has been used to study the martensite formed in a number of plain carbon and alloy steels. This investigation has shown that two distinct types of martensite may be produced on quenching. In high-carbon steels and in a 20%Ni–0·8%C steel the transformation product consists of plate-like grains of martensite, which are internally twinned on a fine scale. The detection of these fine twins, together with the crystallographic data which can be obtained from thin foils, provide experimental verification of certain assumptions made in the recent phenomenological theories of martensite formation. In low-carbon steels and in an 18–8 stainless steel the martensite is in the form of laths or needles, with no trace of internal twinning. This type of martensite is not treated by current theories, and a transformation mechanism applicable to this case is proposed. The variation in morphology and substructure of the martensite produced in different steels is used to explain certain aspects of the mechanical properties of martensite and its behaviour during the early stages of tempering. The factors governing this change in morphology are discussed and some evidence for the mechanism of the stabilization of austenite is presented. 1921

INTRODUCTION

WHEN STEEL IS COOLED RAPIDLY from the austenitic region, transformation occurs at low temperatures and this leads to the production of a new phase, martensite. The mode of transformation is such that a series of co-operative atom movements occurs, each of which is small compared with the atomic diameter.

In order to study the austenite–martensite reaction a variety of metallographic and X-ray diffraction techniques have been used.[1] The results obtained provided a basis for early theories of the atom movements involved in the reaction, but the more refined theories of the transformation require experimental evidence, which could not be obtained by conventional methods. With the advent of the thin foil techniques for examining metals by transmission in the electron microscope it is now possible to study the structure of martensite in detail. As a result new information has been obtained which has led to a better understanding of the austenite–martensite reaction and the properties of the transformation product.

To examine metals by transmission in the electron microscope a specimen is required having a thickness of about 1000 Å. Such specimens can be prepared by controlled electropolishing of a metal sheet 100 μ thick, but for examining martensitic structures the chief experimental problem is the preparation of this sheet. Kelly and Nutting[2] have shown how this may be achieved by electrolytic jet machining of specimen blanks having an initial thickness of 0·5–1 mm. A further advantage of using the electron microscope is the fact that by simple control of the lens current it is possible to obtain electron diffraction patterns from small regions of the specimens. Thus a combination of morphological and crystallographic data can be obtained from the same specimen.

These techniques have been used to study martensites produced in plain carbon steels having carbon contents from 0·1 to 1·4%, in 20%Ni–0·8%C steel, and in 18–8 stainless steel. It now appears that there are two distinct types of martensite: plate-shaped grains containing many narrow twins, and single crystal needles with no evidence of internal twinning. In the present paper the factors governing the changes in martensite morphology are discussed. The relationship between the mechanical properties and the morphology of tempered and untempered martensite, is also considered, and some evidence for the mechanisms by which austenite may be stabilized is given.

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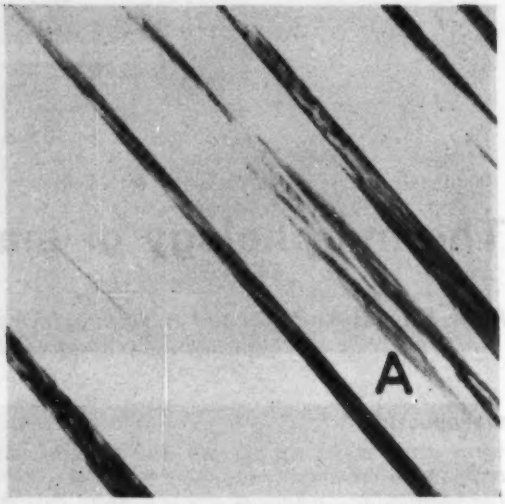
MARTENSITE IN AN Fe–Ni–C STEEL

When an alloy containing 20%Ni and 0·8%C is rapidly cooled from 800°C to room temperature, the structure remains fully austenitic. Sub-zero quenching results in the formation of martensite and the relative amounts of austenite and martensite can be controlled by varying the temperature of the quenching medium. The martensite produced in this way is plate-like and when these plates are suitably oriented, very narrow internal twins are visible, having an average width of about 100 Å and a similar spacing (Fig.1).

The detection of internal twinning on such a fine scale with the aid of the electron microscope is very dependent upon the orientation of the martensite

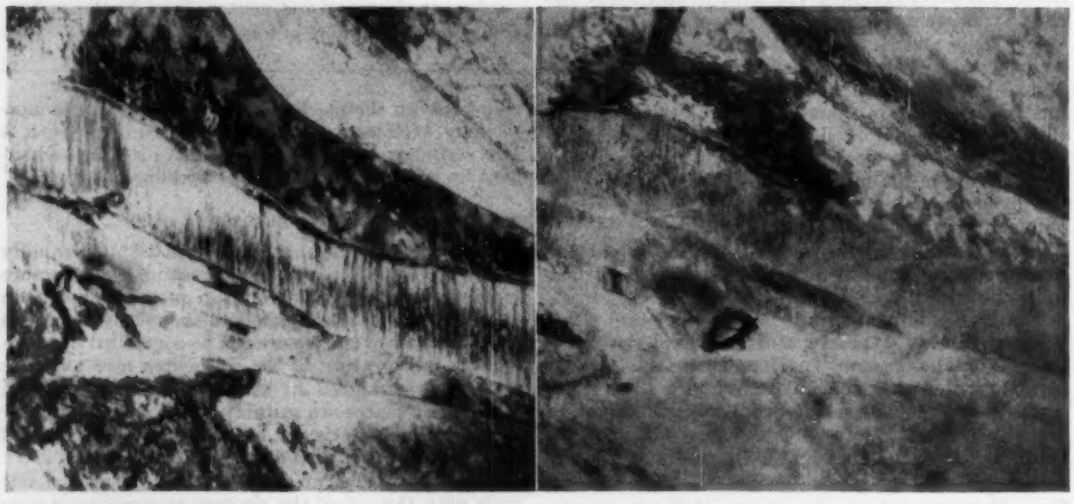
1 *Internally twinned martensite plate in the* Fe–Ni–C *steel quenched to −95°C* ×15000



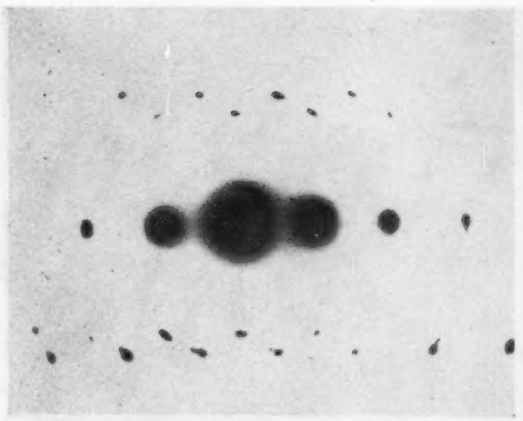
2 *Narrow twins in* Fe–Ni–C *martensite showing fringes at* A ×100000

plates with respect to the electron beam. For a stack of fine twins arranged parallel to the electron beam, strong contrast will be observed when one twin orientation is diffracting the electron beam strongly, while the other is not.[3, 4] When the twins are inclined to the beam, fringes may be produced at the inclined boundary, but these will be easily resolved only if the angle of inclination is large. However, when the angle between the twins and the incident beam becomes too great, neighbouring twins overlap to such an extent that more than one twin of a particular orientation will be traversed by the electron beam and no contrast will be observed. Using rough values of the foil thickness and the twin width, an estimate of the critical angle, above which the twin contrast vanishes, can be made. For different values of the twin and foil thickness, this critical angle ranges from 3° to 12°.

The small value of the range of inclination, for which twin contrast is visible, shows that the chances of resolving fringes at the boundary of an inclined twin are small. In fact this was observed in one or two cases only (*see* Fig.2 at *A*). In addition, even if every martensite plate is internally twinned, the chances of a particular plate showing twin contrast is between one in five and one in twenty. A survey of low-magnification micrographs in the Fe–Ni–C steel quenched to −196°C revealed that 88 plates in 654 showed evidence of twinning. This corresponds to a ratio of one in



3a Fe–Ni–C *steel quenched to −196°C* ×30000 3b *Same area after tilting* ×30000



4 *Twin-related Laue patterns from an internally twinned martensite plate*

seven, which agrees well with the assumption of complete internal twinning. Finally, tilting the foil in the specimen holder (max. tilt 8°) is likely to cause the twin contrast in a particular martensite plate to disappear or become weak, as shown in Figs.3*a* and *b*.

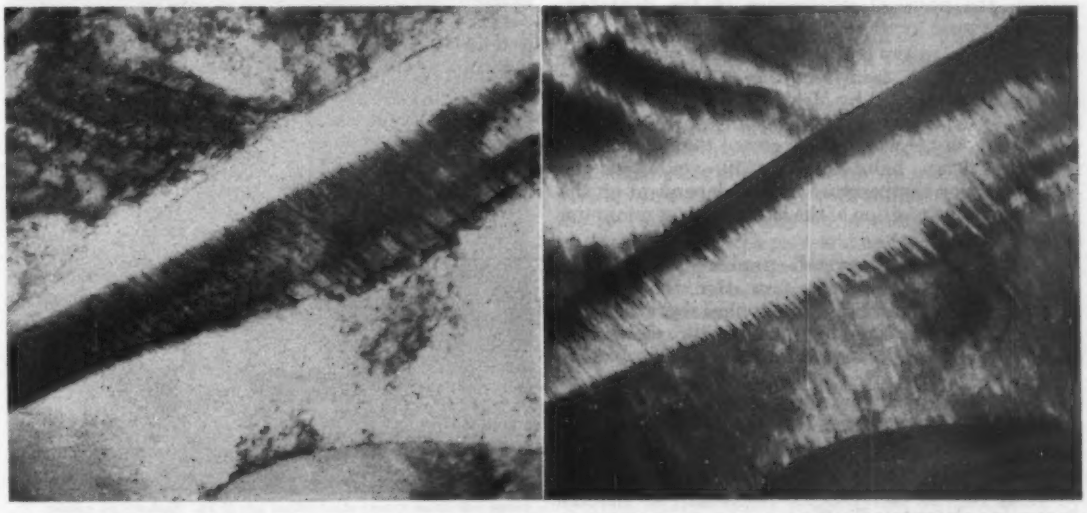
A number of tests were carried out to show that the observed striations did in fact represent twins. First, single surface trace analysis from a number of micrographs and the corresponding diffraction patterns established the twin plane as $\{112\}_M$. Second, diffraction patterns from an internally twinned plate often consisted of two twin-related Laue patterns, as shown in Fig.4. Finally, dark field micrographs obtained by placing the objective aperture over one of the strong, low order diffraction spots from the twins showed reversal of contrast, as shown in Fig.5.

Using the selected area electron diffraction pattern of a particular area, a number of the crystallographic features of the martensite can be determined. Single surface analysis of the trace of a martensite plate can be used to determine the habit plane. This single surface trace analysis is of course not as accurate as the two surface analysis used by previous workers on large specimens. However, it was possible to distinguish between the $\{225\}_\gamma$ and $\{259\}_\gamma$ habit planes in a number of cases, particularly when the martensite plate was nearly perpendicular to the foil. When the martensite plates lay almost in the plane of the foil, and in some cases when the plate was inclined at a large angle to the foil surface, it was impossible to determine which habit plane did in fact occur. No martensite plates were found which gave traces inconsistent with one or other of these two possible habit planes. The orientation relationship between the martensite and austenite can also be found, although electron diffraction is not as accurate as X-ray diffraction for this purpose.

The technique did allow the Kurdjumov and Sachs[5] (*K–S*) and Greninger and Troiano[6] (*G–T*) orientation relationships to be distinguished in a number of cases. Finally, the indices of the austenite plane, which becomes the twin plane in martensite, can be determined. The parent of the twin plane is of importance in connexion with current theories of the martensite transformation, since this plane represents the second shear plane and there is no previous experimental evidence for the operative second shear system.

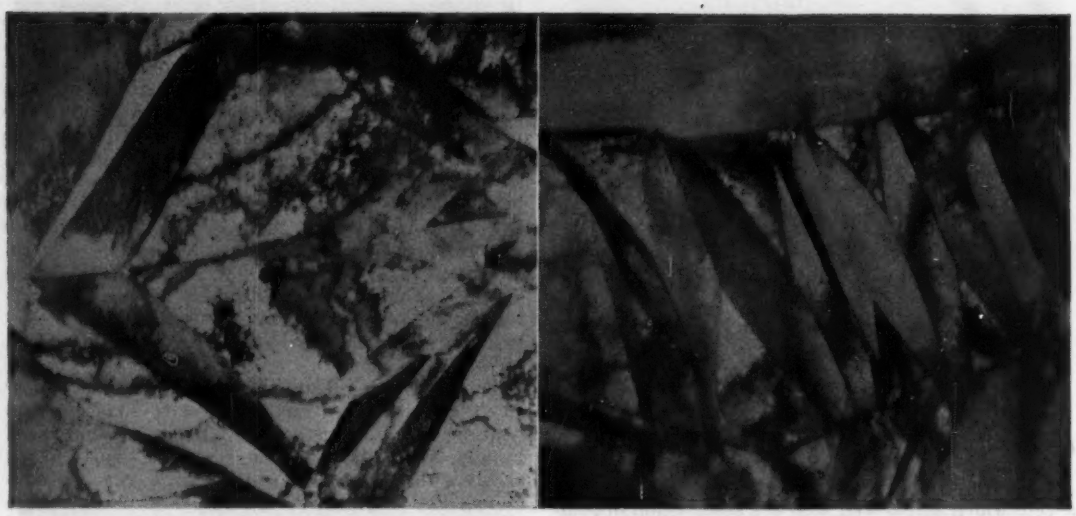
The results of the various crystallographic determinations were as follows. When specimens were quenched to −196°C, the majority of the martensite plate showed the *G–T* orientation relationship and the $\{259\}_\gamma$ habit, while for specimens quenched to −95°C the $\{225\}_\gamma$ habit and *K–S* orientation relationship predominated. In all the martensite plates, whether the habit was $\{225\}_\gamma$ or $\{259\}_\gamma$, the parent austenite plane which gives rise to the twin plane in the martensite was found to be $\{110\}_\gamma$.

In current theories of the martensite transformation[7,8] the second shear system is assumed to be the martensite twinning system $(112)_M$ $[111]_M$ which is derived from $(110)_\gamma$ $[110]_\gamma$. Using this second shear system and the criterion that the habit plane is an invariant plane in both the parent and product



5a *Bright field micrograph of an internally twinned martensite plate in the* Fe–Ni–C *steel* ×36000

5b *Dark field micrograph of the same area, showing reversal of the twin contrast* ×36000



6 *'Chevrons' of martensite plates formed in the* Fe–Ni–C *steel* ×17000

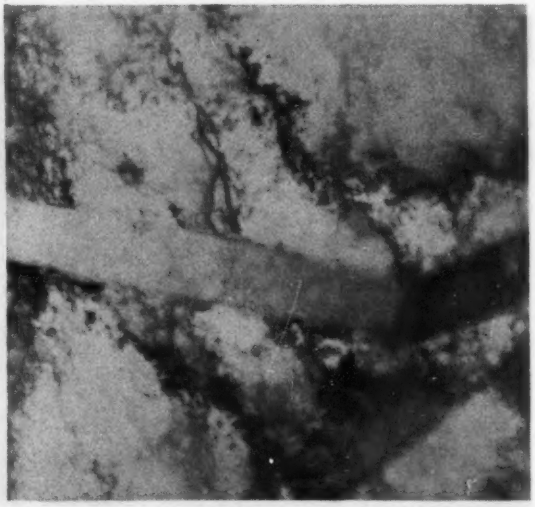
7 *'Co-operative' arrangement of martensite plates in the quenched* Fe–Ni–C *steel* ×20000

lattices, martensite plates with the $\{259\}_\gamma$ habit and the *G–T* orientation relationship can be predicted. However, in the case of the {225} habit and the $K–S_\gamma$ orientation relationship the various theoretical treatments differ. Wechsler *et al.*[9–11] consider that the action of an alternative second shear system is responsible for this habit, while Bowles and MacKenzie[8] introduce an adjustable uniform dilatation into the transformation strain and so provide their analysis with the additional degree of freedom required to predict the $\{225\}_\gamma$ habit. Besides verifying the second shear system assumed by Bowles and MacKenzie, the present thin foil study has shown that the same system is operative in martensite plates with both the $\{225\}_\gamma$ and $\{259\}_\gamma$ habits. Hence the Bowles–MacKenzie treatment of the transformation must be substantially correct. In view of this an attempt has been made to explain the physical significance of the dilatation parameter used by these authors.[12]

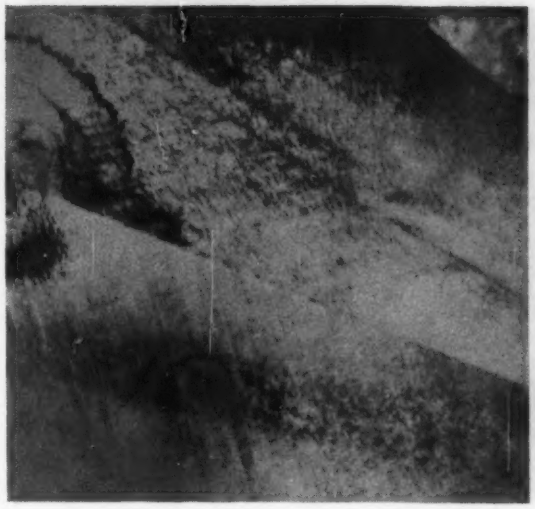
The change in the predominant habit plane with a variation in the transformation temperature has already been reported by Mehl and Van Winkle[13] and a possible explanation for this change has been proposed by Kelly,[14] who has suggested that the change from the $\{225\}_\gamma$ habit to the $\{259\}_\gamma$ habit, as the transformation temperature falls, is dependent on the variation in the position of the habit plane at minimum strain energy.

Besides providing crystallographic data relevant to the theories of martensite formation, the study of thin foils of martensite in this alloy has revealed other interesting features. When martensite plates are observed near a grain or twin boundary in the austenite, another plate is often nucleated at the other side of the boundary. In a few cases these two martensite plates are so oriented that they appear as one single plate with a boundary in the middle. However, the two plates are usually at an angle to each other, resulting in the familiar 'chevron' arrangement of martensite plates (*see* Fig.6).

As the course of the martensite reaction proceeds the regions of austenite which have not yet transformed become smaller. Martensite will form more easily in one of these confined regions if the plates are in pairs, with the deformation in one plate in the pair counteracting the distortion caused by the other plate. This gives rise to the 'co-operative' grouping of martensite plates shown in Fig.7, where the region of austenite which has transformed was originally bounded by an austenite grain boundary and a large martensite plate. In direct contrast to this is the arrangement of martensite plates found in a specimen that had been partially transformed by deformation at room temperature. The criterion governing the arrangement of the martensite plates in this case is that of maximum relief of the applied stress. This is best achieved when the deformation produced by each



8 *'Bracket' martensite in the* Fe–Ni–C *steel deformed 19% in tension at room temperature* ×30000



9 Fe–Ni–C *steel quenched to −196°C showing two martensite plates with different orientations in contact* ×40000

11 *Martensite produced by deforming stainless steel in liquid nitrogen* ×30000

martensite plate has at least a large component in the direction of this stress. This leads to the production of martensite plates joined in pairs at an obtuse angle (*see* Fig.8). This arrangement has been termed 'bracket' martensite by Maksimova and Nikonorova.[15]

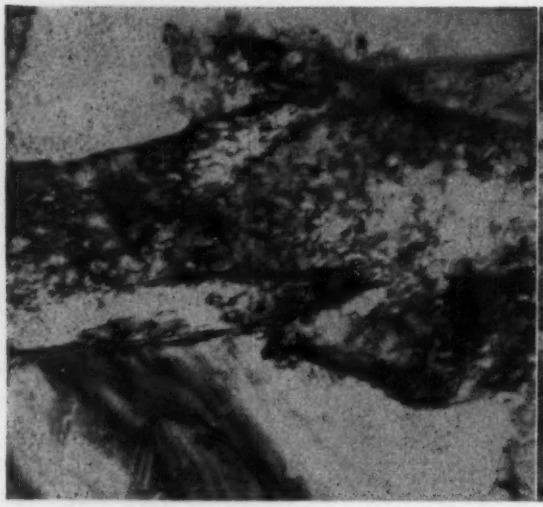
Although an extensive search was made, no evidence of any discontinuity, which might represent the martensite 'mid-rib', was found in any of the martensite plates. However, there was one feature of the arrangement of martensite plates, which might provide an explanation of the 'mid-rib'. In a number of areas, groups of two or more plates were found in contact with each other. The boundary between the two plates was always straight and the plates were often in contact along most or all of their length. Two different arrangements of pairs of plates were found. In the first of these the orientation of the plates differed. This was visible as either a difference in contrast or a difference in the direction of the twins (*see* Figs.9 and 10 at *A*). Such pairs of plates must have different habit planes, and most likely arrangement is such that the two habit planes are adjacent ones such as $(225)_\gamma$ and $(259)_\gamma$, $(529)_\gamma$ and $(259)_\gamma$, or $(225)_\gamma$ and $(529)_\gamma$. In this case the boundary plane is probably the common unrotated plane $(111)_\gamma$. Owing to the difficulty of determining the habit plane uniquely from a single surface trace analysis, only two pairs of plates with differing orientations were shown conclusively to have such a pair of habits and in both cases the trace of the boundary plane was consistent with $(111)_\gamma$.

10 Fe–Ni–C *steel quenched to −196°C, showing martensite plates in contact. At* B *the martensite plates have the same orientation and at* A *the orientation of adjacent plates differs* ×20000

The other arrangement occurred when both plates had the same orientation, as shown in Fig.10 at *B*. Both plates now have the same habit plane and the boundary plane is parallel to this common habit. The plates are presumably formed separately and grow together with a slight misorientation caused by the distortion of the intervening austenite. Under the optical microscope such a pair of plates would appear as a single plate with a 'mid-rib' no matter how they were sectioned. For a pair with different orientations, the two plates will only be in complete contact for certain sections of the pair, and under these conditions the pair may again appear as a martensite plate with a 'mid-rib'. For other sections this arrangement will be recognized as two distinct plates, even under the optical microscope. An examination of the published micrographs of martensite agree well with these considerations.

MARTENSITE IN AN 18–8 STAINLESS STEEL

Only a small amount of martensite is produced when stainless steel is quenched in liquid nitrogen, but the amount of martensite formed can be increased by deformation at this temperature. The method used to produce the transformation seems to have no effect on



12 *Stainless steel quenched to −196°C, showing high dislocation density in a martensite needle* ×60000

13 *Sheet of martensite needles produced by quenching stainless steel to −196°C* ×95000

the character of the martensite. In both the martensite produced on quenching and that obtained by deformation, the grains were small, often less than 1 μ in length. In contrast to the plates of martensite observed in the Fe–Ni–C steel, the martensite in stainless steel appeared as needles with no evidence of internal twinning. All the needles gave electron diffraction patterns of a body-centred cubic lattice and no hexagonal ϵ-phase was detected. The appearance of the martensite is shown in Fig.11.

The complete absence of internal twinning was confirmed in two ways. First, a large number of martensite grains were studied yet none of the diffraction patterns from a single needle showed twin spots. Second, dislocations were readily visible in the interior of the martensite grains (*see* Fig.12). When internally twinning is present in a martensite grain the dislocation contrast is effectively masked by the twins, even if these are showing no contrast. Hence the appearance of dislocations in the majority of the martensite needles in this alloy is strong evidence for the absence of internal twinning.

There was a tendency for complete grains or twins in the parent austenite to transform completely to martensite. This made a measurement of the orientation relationship difficult. However, it was possible to show that the orientation relationship obeyed was that found by Kurdjumov and Sachs[5] in high-carbon steels. To confirm that the needle-shaped grains seen in the foils did in fact represent true needles and not sections of plates, trace analysis of both the long axis of the needles and of the normal to this direction were carried out. If these martensite grains were in fact plates at a large angle to the foil surface, then the trace of the normal to the long axis should be consistent with some habit plane, while the long axis itself might be any direction in this plane. However, exactly the opposite behaviour was found. The longest direction of the grain was always close to or coincident with $\langle 11\bar{1}\rangle_M$, which is parallel to $\langle 1\bar{1}0\rangle_\gamma$, while the traces of the normal to this direction did not consistently pass through any one point on the stereogram. Hence the martensite grains visible almost certainly represented needles and not plates.

Another curious feature was the marked tendency for the needles to lie in sheets parallel to $\{101\}_M$ (Fig.13). The needles in the sheet were always twin-related to each other with the same direction normal to the sheet in each twin. Occasionally sheets containing more than one group of parallel needles were found, as shown in Fig.14. The different groups of needles were at 60° to each other, and since the long axis of the needles was $\langle 1\bar{1}0\rangle_\gamma$ the plane of these sheets of needles must be $\{111\}_\gamma$.

The formation of twin-related needles parallel to $\langle 1\bar{1}0\rangle_\gamma$ and lying in sheets in $\{111\}_\gamma$ is not explained by the current theories of the transformation. This is not surprising since these theories are aimed at producing an invariant plane between the two phases, while the governing condition in this case seems to be the production of an invariant line, which is in fact the long axis of the needles.

A mechanism of martensite formation which is appropriate to this case can be proposed. This mechanism is a modification of that proposed by Kurdjumov and Sachs[5] and consists of a shear on $(111)_\gamma$ in the direction $[1\bar{2}1]_\gamma$, followed by a shear on the plane $(1\bar{2}1)_M$, which is produced from $(\bar{1}\bar{1}3)_\gamma$, in the direction $[11\bar{1}]_M$, together with an expansion of 8·9% perpendicular to $(1\bar{2}1)_M$. Both these shears are homogeneous throughout the whole of the martensite needle, and the second shear may be more correctly regarded as an invariant plane strain on $(1\bar{2}1)_M$. The martensite grains produced by this mechanism will be single crystal needles parallel to $[11\bar{1}]_M$ (or $[1\bar{1}0]_\gamma$) and twin-related needles will arise if the first shear in adjacent needles occurs in different $\langle 121\rangle_\gamma$ directions lying in the plane $(111)_\gamma$. A mere reversal of the direction of the second shear will not produce twin-related needles and the parent of the second shear plane is not a plane of symmetry in the austenite lattice. Hence it is impossible to build up an internally twinned martensite plate. It is,

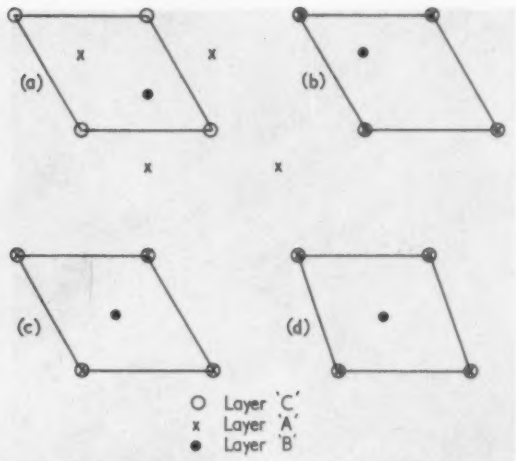
14 *Sheet of martensite needles produced by deforming stainless steel at −196°C. (Note that the needles are arranged in two independent groups inclined at 60° to each other.)* ×24000

however, possible for the twin-related needles to lie in sheets parallel to $(111)_\gamma$, since this plane is an unrotated plane in both twin orientations.

A further consequence of the formation of martensite in this way is the possible role of stacking faults as nuclei or embryos for the martensite needles. This can occur in the following way. The proposed mechanism involves a first shear, which is in fact half the stacking fault shear. Further, an examination of the atom positions in the fault shows that the close packed planes above and below the faulted plane are in fact in the same positions as they would be, if the first shear of the proposed mechanism had occurred on the plane immediately below the fault. The atoms in the fault need only be shifted by a small amount 1/12 **a** [112] and the result will be three close packed planes, in which the atomic arrangement is the same as that of austenite, which has undergone the proposed first

TABLE I Observed behaviour of various steels

Alloy system	Effect of prior deformation	Refs.	Presence of stacking faults	Refs.
Fe–Ni	Retardation at 5% strain	18	Few faults if any	25
Fe–Ni–C	Very slight stimulation for small strains; retardation at large strains	19	No faults after quenching; some faulting after deformation	25
Fe–Ni–Cr	Pronounced stimulation for small strains; retardation at strains greater than 12%	20 24	Considerable faulting	25
Fe–Mn–C	Very slight stimulation (if any), at small strains; strong retardation at large strains	19 23	No faulting except after deformation at 4°K	25
Fe–Cr–C	Stimulation for small strains; retardation at large strains	21	Good evidence for faulting	25
Fe–Ni–Mn	Strong retardation at all values of strain	22 23		
Fe–Mn			Some evidence for faulting	25



15 *Atomic arrangement of three close packed layers of* (a) *perfect austenite,* (b) *faulted austenite,* (c) *austenite after the proposed first shear, and* (d) *body-centred cubic martensite*

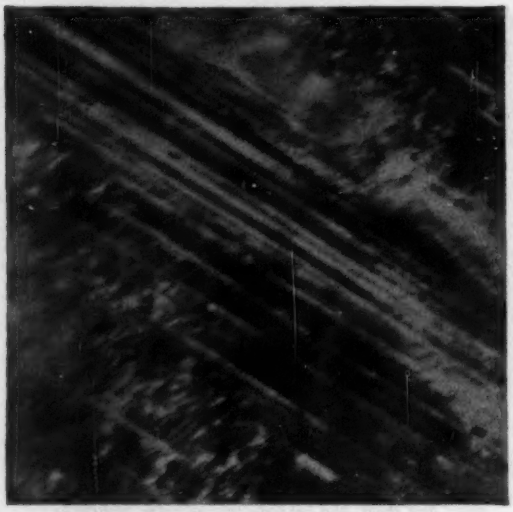
shear. This is shown in Fig.15. Overlapping stacking faults on every alternate plane produces the hexagonal structure, and if the atoms on each fault plane were to shift by the required amount and then follow the proposed second shear system, the body-centred cubic structure would result.

This action of stacking faults in providing nuclei for the martensite transformation in stainless steel is consistent with the presence of an intermediate hexagonal ϵ-phase as found by a number of workers. It is worth noting that single faults or groups of faults on parallel planes are not likely to act as nuclei for the more conventional type of transformation which leads to the formation of martensite plates with either the $\{225\}_\gamma$ of $\{259\}_\gamma$ habits. However, there is some evidence that martensite plates can be formed at the junction of two intersecting bundles of faults.[16,17]

Further confirmation of the nucleation of martensite needles at stacking faults is shown by the fact that if stainless steel is deformed a few percent at a temperature above its M_s, the transformation on cooling is greatly stimulated. This stimulation of the transformation by small amounts of prior deformation has been the subject of considerable study, chiefly by Russian workers.[18–24] The behaviour of all the alloys investigated to date falls into one of two classes:

(i) alloys in which the transformation is always retarded by prior deformation, regardless of the extent of this deformation
(ii) alloys in which the transformation is stimulated by small amounts of prior deformation and retarded by large deformations.

If stacking faults are responsible for this stimulation, then the alloys which exhibit this effect should have a low stacking fault energy. The data on the stacking fault energy of ferrous alloys is limited, but a comparison of the results of Otte[25] with the observed behaviour of various steels shows considerable agreement, as shown in Table I. The retardation effect, which is observed at high deformations can then be explained in terms of the stabilization of austenite (*see* below: 'The stabilization of austenite').



16 *Internal twinning in* 1·0%C *martensite* ×80000

MARTENSITE IN PLAIN CARBON STEELS

Thin foils of quenched plain carbon steels revealed that two different types of martensite were present.[12] At high carbon contents the martensite consisted of internally twinned plates similar to those found in the Fe–Ni–C steel (*see* Fig.16). The presence of twinning was confirmed using the tests described earlier ('Martensite in an Fe–Ni–C steel'). Since retained austenite was observed only in the 1·4%C steel, and then in very small amounts, very little work could be done on the habit plane, orientation relationship, and parent of the twin plane in the martensite. However, these steels have already been the subject of considerable investigation using X-ray diffraction techniques, and the martensite plates in steels with carbon contents in the range 0·8–1·4% are reported to have the $\{225\}_\gamma$ habit and the *K–S* orientation relationship.[5,26–29] The presence of twinning in plates with $\{225\}_\gamma$ habit is further confirmation of the results obtained with the Fe–Ni–C steel.

In low-carbon steels the martensite consisted of single crystal needles similar to those found in stainless steel (*see* Fig.17). The absence of twinning in these needles is reflected in the Widmanstätten form of the carbide produced on tempering (*see* below: 'The effect of the morphology of martensite on its behaviour during tempering') and the appearance of dislocations in the needles. Single surface trace analysis of the long axis of the needles was consistent with this direction being $\langle 111\rangle_M$, while the traces normal to this were not consistent with any particular plane, showing that the grains of martensite were not likely to be plates lying almost normal to the foil. Previous work on the morphology of low carbon martensite[25,26,28,29] has shown that the grains of martensite are needles parallel to $\langle 110\rangle_\gamma$. Dörnen and Hoffmann[30] have shown that the *K–S* orientation relationship is obeyed in these steels and in this relationship $\langle 111\rangle_M // \langle 110\rangle_\gamma$. Hence the present results are in agreement with those of earlier workers.

There was a slight tendency for the martensite needles to form in sheets with the orientation of the needles in the sheet substantially the same. This tendency increased with carbon content in the range 0·14–0·34%C and in one steel (0·2%C) two sheets of twin-related needles were found. The absence of retained austenite made it impossible to determine the plane of these sheets with any accuracy.

Even in the steel with the lowest carbon content investigated (0·14%C) a few internally twinned martensite plates were seen. The relative numbers of these plates increased with the carbon content, but there was no sign of a gradual change from needles to laths and finally to plates.

The similarity between low-carbon martensite needles and the martensite in stainless steel suggests that the mechanisms of formation are the same in both cases. Bowles[31] suggested that the low-carbon martensite merely represented a degeneration of plates into needles. There is no evidence for this, and in addition, if this proposal were correct the habit plane of a sheet of needles should be $\{225\}_\gamma$ and not $\{111\}_\gamma$ as found by a number of workers.[26,27,29,30] Hence the mechanism of formation of low-carbon martensite needles is almost certainly different from that operative in high-carbon steels.

If the proposed mechanism of martensite formation in stainless steel is applicable to low-carbon martensite there are two possible reasons for the change in morphology with carbon content. First, the stacking fault energy of austenite may increase with the carbon content. This is consistent with the increase in the relative numbers of internally twinned plates with carbon content. On the other hand the change in morphology may be temperature dependent. In the low-carbon steels the M_s temperature is high and as a result considerable tempering occurs during the quench. This autotempered precipitate is never seen in the twinned martensite plates, suggesting that these plates are formed in the low-temperature portion of the transformation range. Since the proposed transformation mechanism for martensite needles involves a relatively large first shear (19·5°) it is possible that this type of transformation would be assisted by the thermal motion of the atoms. Thus, as the transformation temperature range moves to lower temperatures with an increase in carbon content, the percentage of martensite needles will decrease until the M_s is below a temperature at which thermal motion is sufficient to aid the reaction. Below this temperature the martensite will be entirely in the form of plates.

THE EFFECT OF THE MORPHOLOGY OF MARTENSITE ON ITS MECHANICAL PROPERTIES

The present investigation has revealed two distinct types of martensite grains: needles, and internally twinned plates. The plates can be further sub-divided into those with $\{225\}_\gamma$ habit and those with $\{259\}_\gamma$ habit. However, this division will have little or no effect on the mechanical properties of martensite. The single-crystal needles on the other hand should show a different behaviour from the twinned plates, not associated with the shape of the grains, but with the presence or absence of substructure.

In the absence of any substructure a martensite grain will deform in the usual way. However, this is not possible with an internally twinned plate, as the twin boundaries will block dislocation movement. For

17 *Martensite needles in a 0·1%C steel* ×60000

18 *Fe–Ni–C steel quenched to −196°C and then deformed at room temperature, showing deformation twins parallel to the transformation twins and kinking of the boundary at* A ×30000

such a plate to deform as easily as an untwinned grain, the operative slip system must be such that both the slip plane and the slip direction are common to both twins. The only deformation systems which fulfil this requirement consist of the $[11\bar{1}]_M$ direction (which is the transformation twinning direction) and the slip or twin planes which lie in the zone of this direction. Thus the available deformation systems are reduced by a factor of four in the presence of internal twinning. This decrease in the number of possible deformation systems will result in both an increase in strength and a reduction in ductility.

The observed curve of the hardness of quenched steels in carbon content is not linear even in the range of carbon contents where there is little or no retained austenite. This is difficult to explain if the hardness of martensite depends only on the carbon content and the deformation accompanying the transformation. However, when the effect of the increase in the relative numbers of internally twinned plates is included, the observed sigmoidal-shaped curve can be accounted for.[12]

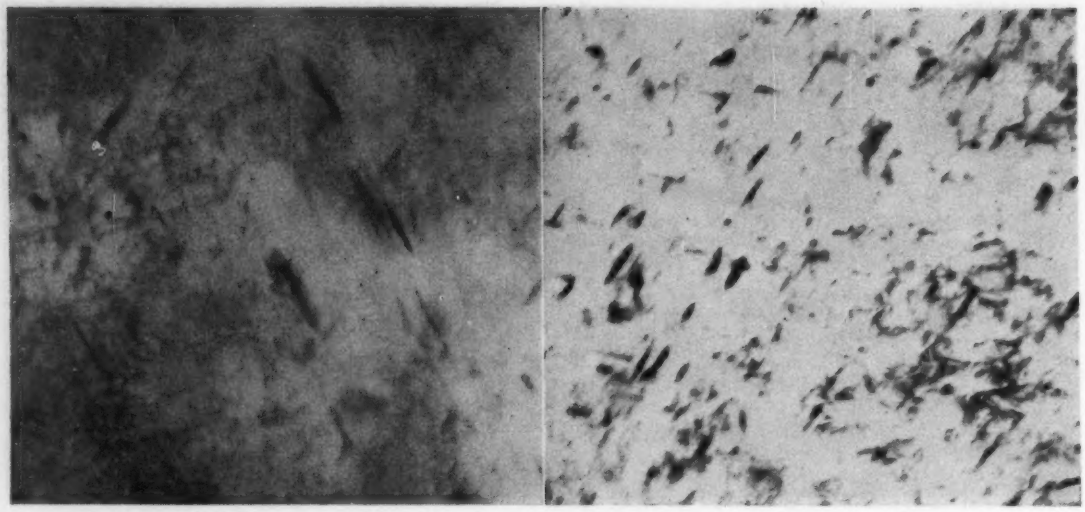
A limited study of the deformation characteristics of martensite was carried out on the Fe–Ni–C steel. The deformation was produced by indenting the specimen in a large number of places with a steel ball. Thin foils of the deformed specimen showed bands 750–1000 Å wide running diagonally across the majority of the martensite plates. These bands were sometimes parallel to the transformation twins and showed similar contrast (*see* Fig.18). Hence, although it was not possible to obtain more direct evidence from the limited number of foils investigated, these bands were taken to be twins. The kinking of the boundary, which would be expected if these bands were twins, was also observed (*see* Fig.18 at *A*).

A martensite plate can deform by the growth of one or other of the transformation twin orientations. In addition there are two other twinning planes which are common to both transformation twin orientations and have the same twinning direction. Hence it is possible for deformation twinning to occur on one of these twin planes and in this case the deformation twins will not be parallel to the transformation twins. This arrangement was also observed and the trace of the deformation twin was consistent with twinning on one of these other two twinning planes. Deformation twinning in martensite is also evident in the optical micrographs of deformed martensite reported by previous workers.[32, 33]

THE EFFECT OF THE MORPHOLOGY OF MARTENSITE ON ITS BEHAVIOUR DURING TEMPERING

Specimens of a 0·14%C martensite (all single-crystal needles) and a 1·0%C martensite (all internally twinned plates) were tempered in the range 100–400°C for 1 h, to investigate the effect of the martensite morphology on tempering. The low-carbon steel was partially tempered during the quench, and showed Widmanstätten plates or laths 100 Å wide and 1500 Å long (*see* Fig.19), the crystal structure of which could not be identified by selected area electron diffraction. Tempering in the range 100–300°C produced little change in the size of the precipitates, but they were identified as cementite after treatment at 300°C. The number of grains which had tempered increased from some 10% after quenching to 100% after heating at 300°C. At 400°C the cementite showed signs of growth and an increase in thickness was evident, as shown in Fig.20.

The high-carbon steel behaved in a different manner. After quenching no carbide was visible, and no change in the microstructure was detected after heating at 100°C, although the hardness of the steel had increased from 910 to 960 DPN. Tempering at 200°C resulted in the appearance of carbides lying along the twins in the martensite, together with tiny precipitates perpendicular to the twin planes, as shown in



19 *Auto-tempered precipitate in 0·1%C martensite* ×40000

20 *Widmanstätten precipitate of cementite in a 0·1%C steel quenched and tempered at 400°C for 1 h* ×40000

Fig.21. Neither type of precipitate gave satisfactory diffraction patterns, so identification was impossible. The small precipitates, which were arranged normal to the twins, were no longer visible after tempering at 300°C, while the lath-like carbides lying along the twins were more predominant, as shown in Fig.22. At this stage the precipitate along the twins was identified as cementite and the orientation relationship found to be:

$(211)\alpha // (001)_{Fe_3C}$
$[0\bar{1}1]\alpha // [100]_{Fe_3C}$
$[1\bar{1}\bar{1}]\alpha // [010]_{Fe_3C}$

This is in agreement with the work of Pitsch and Schrader[34] and shows that the precipitates lie with their longest direction parallel to the twinning direction. The twins themselves were still visible, except where the carbides had grown completely across one twin. Tempering at 400°C produced no further change, except for a slight thickening of the cementite laths and a further decrease in the number of twins present.

Thus the main differences between the tempering of a high-carbon and a low-carbon steel stem from the difference in the substructure in the martensite grains of each steel. In the case of low-carbon steel the martensite is free from substructure, with the exception of dislocations, and the precipitation process proceeds in the usual manner, producing a Widmanstätten arrangement of carbide. However, in the high-carbon steels the presence of internal twinning has a pronounced effect on the distribution of the precipitate. No evidence of strain fields surrounding the precipitates were detected at any stage in the tempering process.

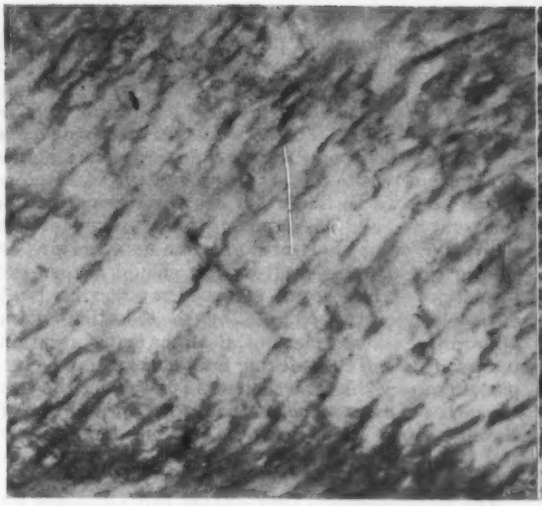
The present work on the early stages of tempering suggests that there are a number of discrepancies in the previous theories of the process. The first of these is the explanation of the lack of change in the hardness of low-carbon steels on tempering up to 200°C. Previously Roberts *et al.*[35] and Cohen *et al.*[36] suggested that in steels with carbon contents below 0·25%C the first formed carbide is cementite, which does not precipitate until the tempering temperature exceeds 200°C. The present study shows that carbide precipitation does occur to an appreciable extent in low-carbon steels and thus an alternative explanation for the delayed softening seems necessary. Since the hardness of low-carbon martensite needles is due almost entirely to the work-hardening produced by the transformation to martensite, no softening should occur until this is removed by recovery at 300°C and above.

The behaviour of a high-carbon steel on tempering also requires some explanation. The initial hardening observed at 100°C is considered to be due to the formation of small, probably coherent precipitates; and the pronounced softening above 200°C, when previous work[35,37] has shown that the carbon content of the matrix is below 0·2%C, is attributed to the growth of the carbides. Since little growth of the carbides is observed between 200° and 400°C this explanation is dubious and instead it seems reasonable to suppose that this softening is due to the removal of the twins, by the cementite precipitates formed along them and also by the growth and agglomeration of these twins.

Direct evidence of the initial hardening mechanism was not obtained in the present work, mainly because the foils from the specimen tempered at 100°C were very poor, but the appearance of the microstructure at 200°C suggests that this hardening is due to the formation of small precipitates, presumably ε-carbide, across the twins, thus locking the only remaining deformation system in an internally twinned martensite plate.

Although the course of the tempering process at temperatures below 200°C requires further investigation, particularly in the case of high-carbon steels, the behaviour at temperatures in the range 200–400°C seems to be fairly well established. Softening in this temperature range can occur by:

(i) the recovery of any deformation caused during the martensite transformation
(ii) the growth of carbides



21 1·0%C *steel quenched and tempered for 1 h at 200°C, showing large precipitates along the twin boundaries, as well as small unidentified precipitates across them* ×100000

22 1·0%C *steel quenched and tempered for 1 h at 300°C, showing cementite laths lying along the twins* ×20000

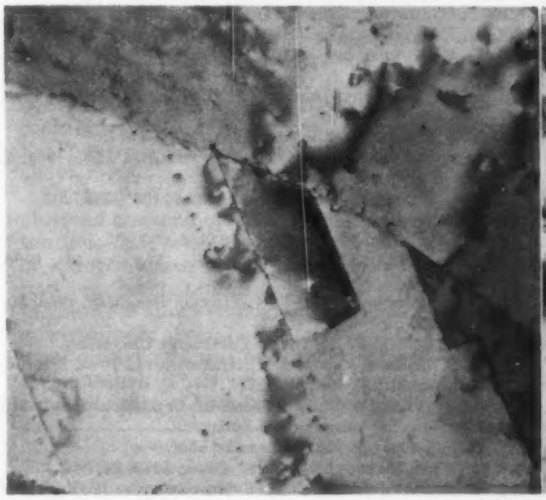
(iii) the removal of any carbides lying across rather than along the twins
(iv) the removal of the twins themselves.

In low-carbon steels twinning is absent and only the first two processes will contribute to the softening, while in high-carbon steels the combination of all these factors will lead to the observed rapid fall in hardness.

THE STABILIZATION OF AUSTENITE

The amount of martensite formed on quenching a steel depends on the stability of the austenite. The stabilization of austenite by mechanical and thermal treatments has been the subject of a number of investigations. If a steel is partially transformed to martensite, the remaining austenite is more difficult to transform and this stability of the austenite is increased by ageing at room temperature and above. The stabilization produced in this way increases strongly with the amount of martensite formed before ageing. Large amounts of plastic deformation before quenching have the same effect as prior transformation on the stability of austenite. Hence it appears that the stabilization produced by prior transformation is connected with the deformation which accompanies the formation of martensite.

The deformation produced when austenite transforms to martensite has been revealed as slip lines in the surrounding austenite.[38] The thin foil technique provides an ideal method for revealing this deformation



23 *Virgin austenite in the* Fe–Ni–C *steel* ×8000

24 *Dislocations surrounding martensite plates in the quenched* Fe–Ni–C *steel* ×30000

directly. In the iron–nickel steel thin foils of the virgin austenite show a structure typical of an annealed material, as shown in Fig.23. After quenching a specimen of the same material to −196°C the retained austenite is found to be heavily deformed (*see* Fig.24). This deformation is greatest in the vicinity of the martensite plates themselves, and in some cases dislocation densities as high as 10^{11} or $10^{12}/cm^2$ were observed. These dislocations have clearly been generated by the distortion which accompanies the transformation.

Since the formation of martensite involves the co-operative movement of atoms, this movement will be more difficult in a distorted lattice, and therefore either prior transformation or prior deformation will increase the stability of austenite. Isothermal ageing increases the stability of partially transformed or cold-worked austenite still further, and this can be explained in terms of the locking of dislocations by carbon as proposed by various workers.[39–41]

Further evidence for the stabilizing effect of plastic deformation comes from the phenomenon of 'super-stabilization'.[15] This is produced by transforming a steel to martensite, retransforming the martensite to austenite and then repeating the cooling cycle a second time. Since both the direct and the reverse transformation result in deformation of the surrounding material,[38] this effect is merely that of severely cold-working the austenite.

Besides deforming the surrounding austenite, the formation of a martensite plate should also result in the deformation of the martensite itself. In the internally twinned plates the twinning obliterates any dislocation contrast; however, in the single crystal needles of martensite, deformation of the product phase is visible (*see* Figs.12 and 17).

The effect of prior deformation on the martensite transformation has been shown to be of two types. In certain alloys the transformation is always retarded (*see* Table I) and this is consistent with the role of plastic deformation in stabilizing austenite.

However, in some alloy systems the transformation is stimulated at small deformation and retarded at large strains. This initial stimulation at first sight appears to be incompatible with the theories of stabilization discussed above. It is also possible that plastic deformation can effect the formation of martensite by providing nuclei of the product phase. For example, previous work[16,17] and the results of the present investigation, show that stacking faults can act as nuclei for the formation of martensite in stainless steel. If the observed stimulation is due to the presence or absence of faults, then the behaviour of stainless steel deformed before quenching can be explained in the following way. At low deformation broad stacking faults are present, and these can act as nuclei for the transformation. As the amount of prior deformation increases the number of stacking faults will increase, but their width will decrease, because of mutual interaction of the partial dislocations limiting the faults. Under these circumstances the faults are less effective as nuclei and the tangled dislocation networks hinder the propagation of the martensite. At very large deformations the stabilizing effect of the dense dislocation tangles will predominate over the stimulating effect of the stacking fault nuclei and the transformation will be retarded.

CONCLUSION

The present paper has described some of the recent results of the study of martensite using the thin foil technique. These investigations have revealed two main types of martensite grain which appear to have different properties. Further experimental evidence is necessary to determine the exact factors governing the type of martensite formed. However, the two factors which seem to be important are the transformation temperature, and the stacking fault energy of the alloy. Lowering the transformation temperature or raising the stacking fault energy should favour the formation of martensite plates. The stacking fault energy can only be varied by the addition of an appropriate alloying element. Both the transformation temperature and the stacking fault energy may be important, and if this is so then it is possible for the two effects to counteract one another. Thus the addition of chromium to a steel lowers the stacking fault energy and the transformation temperature, and thus produces opposing tendencies.

The transformation temperature can be varied by alloying, or by prior deformation. Thus prior deformation of a low-carbon steel, which transforms to martensite needles, should lower the M_s temperature if the deformation is high enough. Subsequent transformation should therefore produce platelike martensite and the strength of this quenched steel should be greater than that of the normal martensite of the same carbon content. This effect has been reported by Shyne *et al.*[42]

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Internal friction effects in iron–silicon–nitrogen alloys

R. Rawlings, Ph.D., F.I.M., and P. M. Robinson, Ph.D.

INTRODUCTION

That nitrogen in ferrite causes a maximum in the internal friction temperature curve is now well known.[1–4] Binary alloys have been almost exhaustively studied but not so much is known of the internal friction of ternary alloys.

For iron–nitrogen alloys with additions of Cr, V, Si, or Mn a second internal friction peak has been observed in addition to and at higher temperatures than the first peak.[5–9] This second peak is generally attributed to stress-induced movement of the nitrogen atom from a Fe–X interstice to a Fe–X interstice, where X is the added substitutional element. The first peak is accepted as being due to movement from a Fe–Fe interstice to a Fe–Fe interstice as in the binary alloys.

In the case of Fe–V–N alloys Fast and Meijering[8] observed a second peak at a higher temperature than the first. They suggested that it was due to movement of nitrogen atoms in and out of distorted interstitial sites near precipitate particles. Leak *et al.*[9] investigating Fe–Si–N alloys found peaks at 21°, 37°, and 62°C at a frequency of about 1 c/s. The peak at 62°C was somewhat elusive and was not observed for all the specimens tested. Their explanation for the peak was similar to that of Fast and Meijering.

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SYNOPSIS

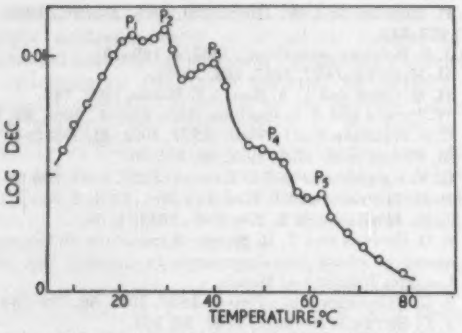
The internal friction of Fe–Si–N *alloys has been investigated at frequencies of 0·74–10 c/s. Three, and in some cases five peaks in the internal friction/temperature curve were observed. The first peak is identical with that for* Fe–N *alloys, the second is associated with* N *atoms and dislocations, and the third with* N *atoms with a neighbouring* Si *atom. It is suggested that the fourth is due to* N *atoms near other* N *atoms. No explanation is given for the fifth peak.* 1907

Leak *et al.* used a 2·83%Si iron alloy quenched from the alpha range. The present investigation was undertaken to investigate the internal friction effects in Fe–Si–N alloys of lower silicon content quenched from the gamma range and from the alpha range.

EXPERIMENTAL

Alloys were made in a vacuum resistance furnace from high-purity iron kindly supplied by the British Iron and Steel Research Association and 99·9% silicon (chief impurity iron). The analysis of the iron was given by BISRA as: 0·0034%C, 0·0025%Si, 0·005% Mn, 0·005%S, 0·001%P, 0·0017%O, and 0·0035%N. The alloys made contained 0·5%, 1·1%, and 1·9%Si respectively. These were processed to 0·027-in dia. wire, which was used for internal friction tests.

The method of adding nitrogen to the wires was to heat in partly cracked ammonia or in nitrogen–



1 *Internal friction/temperature curve for* 1·1%Si *alloy quenched from* 1050°C

hydrogen mixtures. The former was obtained by passing anhydrous ammonia through a heated steel tube, the degree of cracking being controlled by the rate of flow of gas and by the temperature of the steel tube. The variation in temperature along the length of the specimen during nitriding was ±5°C.

The internal friction was determined by observing the rate of free decay of a torsional pendulum in which the specimen was the torsional element. For frequencies of less than 2 c/s visual observations were made with a lamp and scale, while above 2 c/s a photographic method was used. All determinations were made as soon as possible after quenching from the heat-treatment temperature.

For some specimens the shear modulus relative to that of iron was determined using the same apparatus:

$$G_{FeSi}/G_{Fe} = (L/f^2)_{FeSi}/(L/f^2)_{Fe}$$

where G is the shear modulus, L the length of specimen (about 5 cm long), and f the frequency of vibration. L was determined to ±0·002 cm and f to ±0·1%. The overall accuracy of G_{FeSi}/G_{Fe} was probably about 0·5%.

The activation energies for each peak were determined in the usual way from the shift in peak temperature with frequency. At the peak temperature

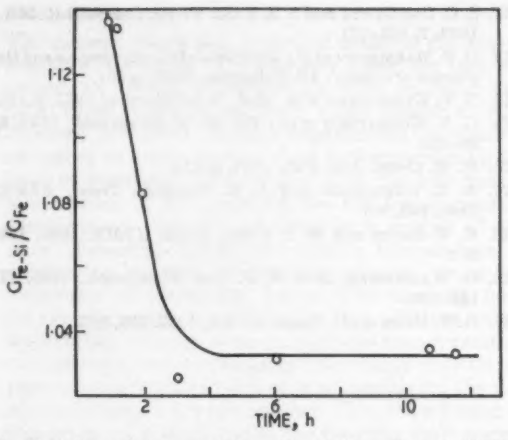
$$\omega\tau = 1$$

where $\omega(=2\pi f)$ is the angular frequency and τ the relaxation time. From the variation of the latter with temperature one can calculate the activation energy H, since

$$\tau = \tau_0 \exp H/RT$$

where τ is the absolute temperature.

The heat treatment of the specimens is given with the results for the sake of continuity. Before nitriding all specimens were heated for 18 h at 900°C in hydrogen. This effectively decarburized and denitrided the specimens as judged by the absence of internal friction peaks due to C and N.



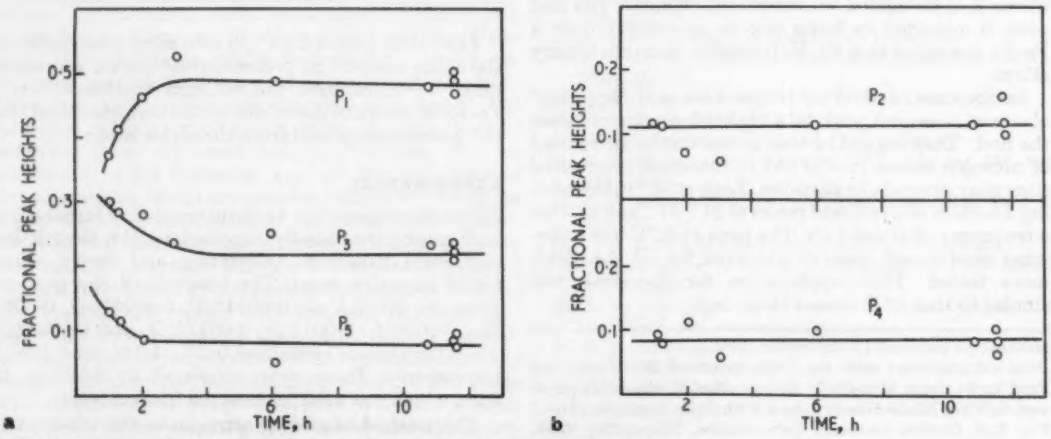
3 *Variation of shear modulus with nitriding time at* 1050°C (1·1%Si *alloy*)

RESULTS

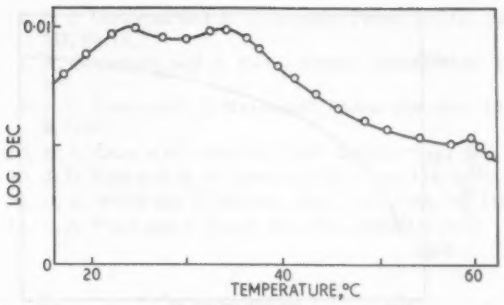
Alloys quenched from temperatures in the gamma range

Wires containing 1·1%Si were heated for up to 20 h at 1050°C in nitrogen–hydrogen mixtures, the internal friction/temperature curve being determined after various times of heating at 1050°C.

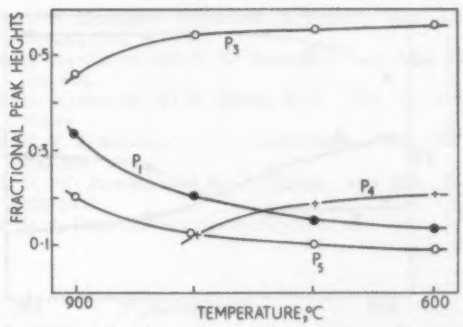
Peaks were observed in the internal friction/temperature curve at 21·5°, 29°, 40°, 54°, and 62°C when the frequency of vibration was 0·93 c/s (Fig.1). The curve could be resolved into five separate curves



2 *Variation of fractional peak heights with nitriding time at* 1050°C (1·1%Si *alloy*)



4 *Internal friction/temperature curve for* 1·1%Si *alloy quenched from 900°C*



5 *Effect of annealing temperature (annealing time 10 min) on the fractional peak heights*

having single relaxation times, the activation energies being given in Table II. In order to follow the changes in relative peak heights it is convenient to use 'fractional peak height'. This we define as the height of any peak divided by the sum of the peaks. The variation of fractional peak heights with nitriding time at 1050°C is shown in Fig.2.

For all these tests, the sum of the peak heights and, presumably, the nitrogen content remained constant. P_1 increased while P_3 and P_5 decreased with time at 1050°C. As far as can be ascertained P_2 and P_4 remained constant. The shear modulus at first decreased and then remained constant after approximately 4 h (Fig.3).

Alloys quenched from temperatures in the alpha range

Nitrided samples of 0·5%, 1·1%, and 1·9%Si iron all showed peaks at 25°, 35°, and 62°C (f=1·03 c/s) corresponding to P_1, P_3, and P_5 for samples quenched from 900°C (*see* Fig.4). The slight disagreement in peak temperatures may be attributed to strains arising from the gamma to alpha transformation. The effect of strain on peak temperature has been observed previously by Leak.[18]

The variation in peak temperature with frequency was determined (*see* Table I) and the activation energy calculated in the usual way (*see* Table II). It was found that the experimental curve could be resolved into three simple curves using these activation energies. The activation energy for P_1 agrees with previous estimates for the peak due to nitrogen in iron.

The higher activation energies for P_3 and P_5 when the specimens were quenched from 1050°C can only be attributed to internal strains in the latter.

A specimen nitrided at 900°C and containing 0·015%N (roughly) showed internal friction peaks at 25°, 35°, and 62°C. However, after heating for 10 min at 800°C and retesting, an additional peak was observed at 54°C, corresponding to P_4. The fractional peak height of P_4 increased as the reheating temperature was decreased (*see* Fig.5).

In another series, specimens were nitrided at temperatures of 600–900°C for times up to 100 h. The peak heights decreased during this time, indicating that precipitation was taking place. The total peak height reached a constant value which varied with temperature. Since the peak height is a measure of the nitrogen in solution, this state is regarded as corresponding to the completion of precipitation. We are, however, concerned here only with the change in fractional peak heights with temperature shown in Fig.6. Note that P_4 was not observed in this series (*cf.* Fig.5 for short heating times). The variation of shear modulus with nitriding temperature is shown in Fig.7.

TABLE I Change in peak temperature with frequency of vibration

Frequency, c/s	Peak temperature, °C P_1	P_3	P_5
0·74	21	29	58
1·03	25	35	62
2·00	28	37	67
3·00	36	53	...
4·70	42	54	77
7·00	47	58	...
10·00	55	62	...

DISCUSSION

The peak P_1

The activation energy of 18300 cal/g atom and the value of D_0 of $6{\cdot}3\times10^{-3}$ cm²/s agree well with values of 18600 cal/g atom and $6{\cdot}6\times10^{-3}$ cm²/s, found by Fast and Verrijp[10] for iron–nitrogen alloys. The corresponding values found by Leak *et al.*[8] for iron–silicon–nitrogen alloys were 18000 cal/g atom and $3{\cdot}1\times10^{-3}$ cm²/s. It is evident that P_1 is due to the movement of nitrogen atoms to and from Fe–Fe sites in the lattice.

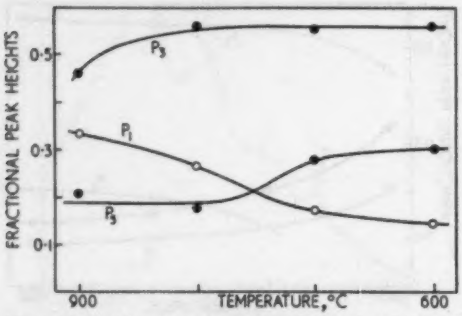
The peak P_3

The authors accept the suggestion of Leak *et al.*[8] that this is caused by movement of nitrogen atoms to and from Fe–Si sites.

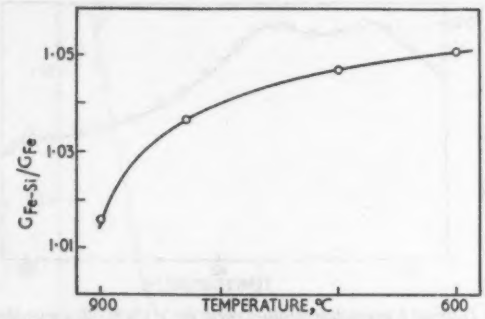
The variations in height can be explained if it is postulated that the fraction of bonds that are Fe–Si change with time and temperature. This is equivalent

TABLE II Activation energies

	Specimens quenched from 1050°C		Specimens quenched from 900°C
	From shape of curve	From change in peak temp. with frequency	From change in peak temp. with frequency
P_1	18300	18300	18300
P_2	80600	...	...
P_3	30000	10000	15800
P_4	42000	...	...
P_5	80000	8470	24000



6 *Effect of annealing temperature (annealing time 70–100 h) on the fractional peak heights*



7 *Effect of annealing temperature on the shear modulus of 0·5%Si alloy*

to a change in degree of short range order (no long range order is involved since no order/disorder temperature has been observed for these silicon contents). The change in shear modulus with nitriding time at 1050°C supports the idea of change in degree of short range order. Barrett[13] has shown that in β brass the shear modulus decreases as the degree of order in the lattice decreases.

The change in the ratio of P_1 to P_3 with nitriding time at 1050°C cannot be ascribed to a process controlled by diffusion of nitrogen, owing to the comparatively long time, 4 h, needed to reach a stable state.

Similarly, it is suggested that increasing temperature in the alpha range decreases the number of Fe–Si sites. This would have the effect observed of decreasing P_3 and the shear modulus (*see* Figs.6 and 7).

The peak P_5

In contrast to the results of Leak *et al.*[9], the present work showed P_5 to be present irrespective of the presence or absence of a precipitate. It was found to decrease with nitriding time at 1050°C indicating that like P_3, it is associated with Fe–Si sites. A second indication of this is given by the increase in P_5 with decrease in annealing temperature in the alpha range.

No explanation can be given of the process giving rise to this peak.

The peak P_2

This was observed when testing specimens quenched from the gamma range but not for those quenched from the alpha range. However, if the latter specimens were strained a small amount ($5{\cdot}6\times10^{-4}$) then the peak appeared on testing. If the specimen was then strained 7% in tension the peak was removed.

These characteristics are similar to a peak at 29°C found by the authors[14] for iron–nitrogen alloys. Since this has been fully discussed,[14] only the conclusion that the peak is associated with dislocations having atmospheres of nitrogen atoms need be stated here.

The peak P_4

This second anomalous peak occurs on quenching from the gamma range. It also occurred on testing specimens containing more than 0·02%N quenched from 900°C (alpha range). For lower nitrogen contents it was not observed after quenching from 900°C. However, when such a specimen was reheated at 800°C for 10 min, and tested, the peak appeared. The peak height increased as the annealing temperature decreased.

From the known solubility of silicon nitride in ferrite[15,16] it appears that P_4 is observed when the ferrite is supersaturated with nitrogen. That is, it appears when nitrogen atoms may be expected to cluster around silicon atoms.

This peak was also found to occur if a specimen was strained small amounts ($2{\cdot}8\times10^{-4}$). This, together with the fact that it appears when it is quenched from the gamma range suggests that it is in some way associated with dislocations.

The peak is thus thought to be due to the movement of nitrogen atoms to and from Fe–Si sites in the presence of another nitrogen atom. This is analogous to the explanation given by Powers[17] for an anomalous internal friction peak in tantalum containing oxygen.

The presence of dislocations or the existence of a supersaturated state would tend to produce such a cluster of nitrogen atoms.

CONCLUSION

Five peaks are observed in the internal friction/temperature curve for Fe–Si–N alloys when quenched from the gamma range and in certain cases when quenched from the alpha range. The peaks are labelled P_1–P_5 in ascending order of peak temperature.

Peak P_1 is identical with that in Fe–N alloys. Peak P_2 is thought to be associated with slow moving dislocations. It is similar to that found under certain conditions in tests on Fe–N alloys.[14]

The peak P_3 (at 35°C at 1 c/s) is probably due to stress-induced movement of nitrogen atoms to and from Fe–Si sites.

It is postulated the peak P_4 (at 54°C at 1 c/s) is due to the stress-induced movement of nitrogen atoms to and from Fe–Si sites, each nitrogen atom interacting with a near nitrogen atom in a similar site.

No explanation is given for P_5 but the previous explanation[9] is not accepted.

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Notes on gas-flow pattern through the regenerative chambers of open-hearth furnaces

Louis G. Septier

SYNOPSIS

Efficient operation of the regenerative chambers of open-hearth furnaces implies as homogeneous a distribution as possible of the gases in the checkers. This distribution depends on numerous and complex aerodynamic factors, among which pressure conditions play a particularly important part. It is shown that the effects of pressure conditions can be isolated by a simplified approach. The conclusions drawn from the theoretical results thus set out are corroborated by practical applications and make it possible to suggest many improvements in the building of the regenerative chambers. 1903

INTRODUCTION

MANY STUDIES have been made[6–14,24,25,27,28] on gas flow in the regenerative chambers of OH furnaces. In all these studies it is concluded that, with production furnaces as well as with small-scale models, the preferential circuits of the gases to be preheated (air, mixed or producer gas) were not identical with those of the preheating gases (waste gases).

In particular, several workers have observed (Fig.1*a*) that the air had its highest speed near the slag pockets, while the waste gases, on the contrary, had their maximum speed near the opposed wall.*

Of course these aerodynamic dissymmetries result in thermal dissymmetries, as shown by Fig.1*b*, since it is obvious that the areas with most waste gases and little air flow are notably hotter than those with few waste gases and much air flow.

In practice, these aerodynamic and thermal dissymmetries seriously inconvenience the running of the regenerative chambers in the following ways:

(i) by increased wear of the refractories
(ii) by reduced thermal efficiency of the heat recovery process
(iii) by increased head-losses in the flow circuits.

In the present paper it is intended to consider in general terms, by calculation, the problem of gas-flow pattern through the regenerative chambers of OH furnaces. The validity of the working hypotheses will then be checked, using examples taken from building improvements already completed. Lastly, in the light of the theoretical results thus obtained, the practical conclusions that may be drawn will be examined.

* However, it is to be noted that some users of OH furnaces observe a more rapid wear of their regenerative chambers close by the slag-pocket wall; this can be explained, on the one hand, by preferential settling of large-grain size dust damaging the bricks in this area through chemical corrosion, and on the other hand by the cooling effect of the outside wall on the bricks of the checkers, which are closer to this wall.

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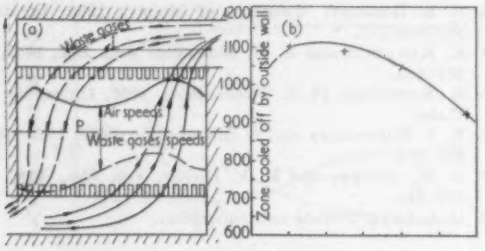
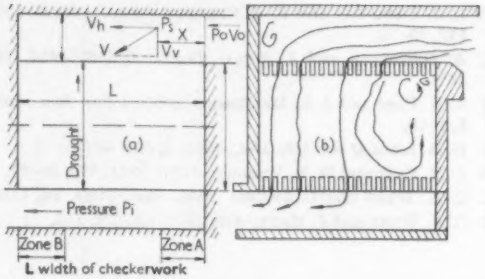
EFFECTS ON GAS-FLOW OF THE PRESSURE CONDITIONS ABOVE AND UNDER THE CHECKERS

Let us consider a vertical 'slice' of a regenerative chamber, parallel with the symmetrical plane of the chambers. Assuming P_s and P_i to be the static pressures at the top and at the bottom of the checkerwork on the vertical line of abscissa X (Fig.2*a*), the vertical speed of the gases going through the checkers will be an increasing function of $(P_s - P_i)$, becoming zero with the latter, and even negative for certain values of P_s and P_i.



a Speed distribution in horizontal plane *P*
b Temperature distribution in horizontal plane *P*

1 *Distribution of the speeds and temperatures in a horizontal section of the checkerwork of a conventional OH furnace, after J. E. de Graaf and G. W. Stein Callenfels*[8]



a Characteristics of a regenerative chamber
b Gas flow diagram, after Luetscher[11]

2 *Main characteristics of gas flows in a regenerative chamber*

A rough estimate of this function might be supplied by the relation:*

$$V_v = \Sigma\sqrt{K(P_s - P_i + T)}$$

in which K and T are constants depending both on the gas (normal specific weight, temperature, etc.) and on the flue walls (width, surface conditions, height, etc.).† This relation is only an approximation to reality but its simplicity is an advantage and it accords with experimental results at least as well as very complex functions resulting from a complete calculation, which is made less effective by the supplementary hypotheses needed for the determination of the integration constants. Lastly, it should be pointed out that such an approximation is valid only in cases in which the thermal dissymmetries have little influence on the aerodynamic flows.

Now let us examine the variation of V_v in the case of a regenerative chamber of conventional construction.‡ Considering for instance, the waste-gas phase: at the top of the checkers, between the latter and the roof, the flow-rate (hence the speed) of the circulating gases decreases as the distance from the slag-pocket wall increases, owing to the flows already engaged in the checkers.

As a result of this reduction of speed, as the distance from the slag-pockets increases, static pressure P_s tends to increase§ (Bernouilli's theorem and experimental results of Fig.3*a*). The reverse symmetrical phenomenon occurs under the checkers where, owing to the speed increase, P_i decreases as the distance from the slag-pockets increases. Lastly, as a first approximation, T may be assumed to be almost constant in the whole checkerwork.‖

Flow conditions in a regenerative chamber of an OH furnace during the waste-gas phase are summarized in Table I*a*. During the air phase, similarly, conditions are as summarized in Table I*b*.

This distribution of pressure above and under the checkers thus creates irregularities in the gas flows through the effect of the driving depression $P_s - P_i$, as the experimental results of Hansen[10] show schematically in Fig.3*a*.

In the case of a particularly defective construction of the regenerative chambers, it could even happen that $P_s - P_i + T$ were negative, which would result in very large aerodynamic unbalances, amounting even to a recycling of the waste gases, as has been shown experimentally[11] (Fig.2*b*).

The conclusions of this statement are entirely corroborated by a more complete calculation¶ which shows that it is possible to express the vertical flow-speed V_v of gases through the checkers as a variable depending on X (distance from the bridgewall) by a function of the following pattern:

$$V_v = \sqrt{\frac{KA}{b}}\ \cos\left[\sqrt{K}\frac{a}{H_e}\sqrt{\frac{\omega}{2}}\,(L-X)\right]^{**}$$

in which b is the ratio of total area of the flues to the total area of checkerwork in an horizontal section, K is the coefficient of permeability of the checkerwork already defined above, A is a numerical datum depending on the flow-rates of the gases going through the

TABLE I Flow conditions in a regenerative chamber

Characteristics	By the wall near the slag-pockets	Wall opposite the slag-pockets
(*a*) *During waste-gas phase*		
Pressure above the checkers P_s	low	high
Pressure under the checkers P_i	high	low
$P_s - P_i + T$	low	high
Vertical speed of gases V_v	low	high
(*b*) *During air phase*		
Pressure above the checkers P_s	low	high
Pressure under the checkers P_i	high	low
$P_s - P_i + T$	high	low
Vertical speed of gases V_v	high	low

* Relation in which the expression $(P_s - P_i + T)$ means: absolute value of $P_s - P_i + T$ and in which Σ, always equal to 1 in absolute value, is algebraically of the same sign as $P_s - P_i + T$.

† Coefficient K denotes the permeability of the checkers to gases. Therefore, any factor tending to increase constant-flow head-losses results in a decrease of K, and coefficient $1/K$ may be considered as representative of the head-losses of the gases going through the checkers. Coefficient T is the weight of a vertical column of the hot gases having a section equal to the area unity and as high as the checkers work.

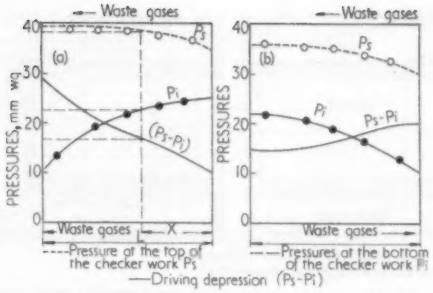
‡ i.e. in agreement with the diagram of Fig.2*a*, and which may have a flat roof, or a cylindrical one with horizontal generators.

§ See detail of calculations in Appendix I, as well as the experimental results of Hansen (Fig.3).

‖ See calculation of T, Appendix III.

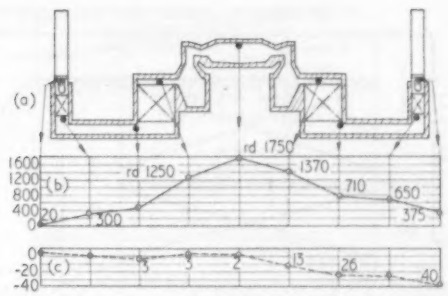
¶ *See* Appendix I

** Formula (18) of Appendix I.



a Conventional regenerative chamber (diagram of pressures)
b Regenerator according to M. Hansen (diagram of pressures)

3 *Variations of static pressures in regenerative chamber of OH furnace, after M. Hansen*[10]



a Diagrammatic section of the furnace
b Temperatures of the fluids
c Pressures of the fluids

4 *Two-stack OH furnace, after E. Goebel and H. Léopold*[7]

checkerwork, H_o is the height of the roof above the checkerwork, ω is the specific mass of the gas, a is the ratio of the actual horizontal speed of the gas to the average horizontal speed in an area close enough to the roof for V_v to be negligible, and L is the length of the checkerwork.

The study of this function confirms that V_v increases when X increases from O (bridgewall) to L (outside wall of the chambers) and that, under certain conditions, it is even possible to have, provided X is low enough, negative values of V_v corresponding to the recycling areas shown experimentally by Luetscher.*

IMPROVEMENT OF GAS DISTRIBUTION IN CONVENTIONAL REGENERATIVE CHAMBERS

Let us consider again the general formula of the preceding section:

$$V_v = \sqrt{\frac{KA}{b}} \cos\left[\frac{a\sqrt{K\omega}\,(L-X)}{H_o}\right]$$

and discuss the terms.

To this end, let us consider the amplitude of the variations of V_v when X varies from O to L, the recycling conditions not being met. It is then possible to write that the relative variations ΔV of V_v are represented by those of the following algebraic expression:

$$\Delta V = \frac{V_v(L)}{V_v(O)} = \frac{1}{\cos \dfrac{a\sqrt{K\omega}L}{H_o}}$$

The gas flows will be the more regular the closer ΔV is to 1 which implies that the parametric expression $a\sqrt{K\omega}L/H_o$ has a value as low as possible.

To this end, it is in practice necessary that:

(i) L be as low as possible: in so far as the arrangement of the premises permits, long and narrow chambers should be avoided, for a given volume of regenerative chambers.

(ii) a be as low as possible: the outlines of the slag-pocket and of the passage between the latter and the regenerative chambers should be such that the distribution of the speeds of the gases above the checkerwork are as uniform as possible.† (With uniform speeds, $a=1$.)

(iii) H_o be as high as possible: the distances between the checkerwork and the hearth on the one hand, and the roof on the other hand, should be high enough for the speed of the gases above and under the checkerwork to be low.

(iv) the permeability coefficient K be as low as possible: a checkerwork with high head-losses will entail a better distribution of the gases than a checkerwork with low head-losses (which can be obtained either by reducing the dimension of the openings between the checker bricks or by increasing the total height of the checkerwork). A number of practical solutions have been proposed which tend to act in this direction and have given interesting results.

Let us examine the more important points.

High checkerwork

Some plants have increased the height of their regenerative chambers. However, as a rule the available space limits the possibilities of a solution in this direction.

Regenerative chambers with double vertical pass

Generally, the regenerators of this type are built as schematized in Fig.8*b*. Although notably increasing head-losses, these regenerators do not appear to have made possible so regular a gas flow as might have been expected.

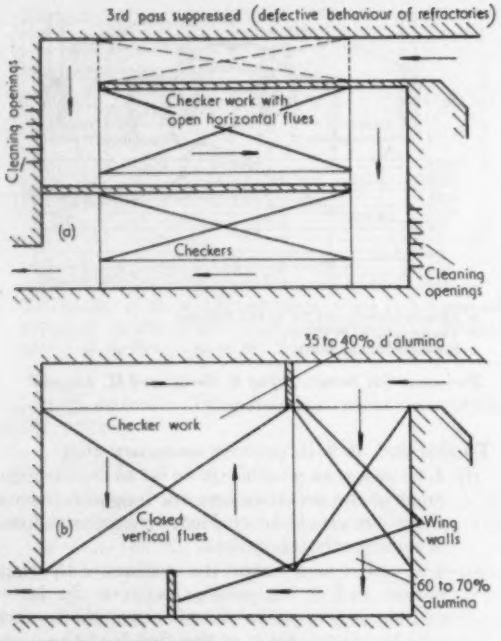
In fact, it is to be noted that for each regenerator, we are brought back to the above-mentioned dissymmetry problem, owing to the presence of the well connecting the two passages. However, for a given

* In fact, the function considered may become negative when X tends towards zero, provided the following condition is met:

$$L > \frac{\pi}{2}\frac{H_o}{\sqrt{aK\omega}}$$

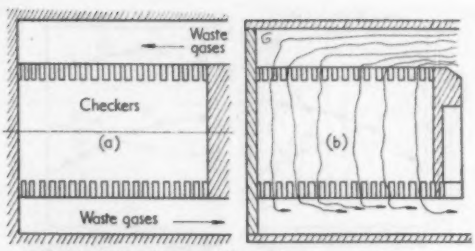
However, as a result of our simplifying calculation hypotheses, it could probably be erroneous to give a quantitative value to these results, which are only meant to define directions of variations, and possibilities of sign changes.

† This remark also implies that, during the 'air' phase, the distribution of the air should be as uniform as possible on its arrival under the checkerwork.



a Two horizontal pass regenerator
b Three vertical pass regenerators

5 *Regenerative chambers with heavy head-losses*



a Construction diagram (Hansen)
b Gas flow diagram (Luetscher)

6 *Improved regenerative chambers according to Hansen[10] and Luetscher[11]*

weight of refractories, thermal exchanges are somewhat improved in such a construction, but on the other hand, the portion of the checkers which first receives the waste gases, requires the use of special refractories to avoid rapid damage.

To this type of construction may be connected the two-stack furnace,[7] (Fig.4), which has given satisfactory practical results, and made possible a definite improvement of thermal efficiency of the OH furnaces in the German steel mill where it was constructed.

Regenerative chambers with double horizontal pass
This type of regenerator has been built for the first time in a UK OH plant.[26] Gas flow is remarkably regular, thermal efficiency is improved in comparison with that of the conventional regenerative chambers operating in the same plant, and lastly, the ease of cleaning provided by this type of construction makes it possible to prevent any fouling of the checkers, which ensures a great regularity of production during a whole campaign. The head-losses of the gases going through these checkers are much higher than with conventional regenerators.

Regenerative chambers with treble vertical pass
These regenerators are built as shown in Fig.5*b*. We have observed this type of construction in a US steel plant.[27] It gives very satisfactory practical results, and thermal efficiency is exceptionally good. The head-losses through such a type of checkerwork are high in spite of the large openings of the checkers.

Checkers with small openings
This system, put into practice by some steelmakers,[27] is most interesting from the thermal standpoint,[25] as it uses checkers with small openings at the top of the checkerwork. This design shows the threefold advantage of (*a*) regularizing gas flow, (*b*) minimizing brick wear in an area where bricks are particularly exposed, and (*c*) increasing thermal exchange through convection. On the other hand, in certain cases, this type of checker shows a tendency to fouling in its upper part; this tendency can be partly reduced by resorting to a closed-flue type construction.

These various types of construction are of practical interest and all have marked a progress in the research of high-efficiency regenerative chambers. However, from the point of view of aerodynamics, they are still somewhat defective and entail heavy head-losses. Therefore other solutions will now be considered which may be more in agreement with the laws of aerodynamics, and which will answer the problem of gas distribution in the regenerative chambers of OH furnaces.

TYPES OF CONSTRUCTION REGULARIZING GAS FLOWS

The equation

$$V_s = \sqrt{K(P_s - P_i + T)}$$

gives a first approximation of vertical speeds.

If it is possible to regularize flow-rates, T will be constant for a brand-new checkerwork, as well as coefficient K, and therefore, on all vertical lines through the chamber, $P_s - P_i = \text{constant}$.

Therefore, it may be expected to regularize gas flows in regenerative chambers by acting in two ways:

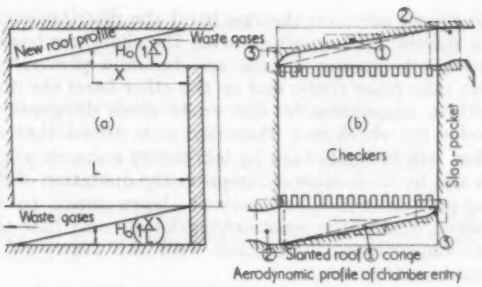
(i) By ensuring that the difference $P_s - P_i$ is independent of X, although P_s and P_i separately may be dependent on X.

The chamber design advocated by Luetscher[11] and Hansen[10] is derived from this type of solution, and is shown in Fig.6.

Effectively, in the direction of increasing X values, P_s increases, but, as the exit is located on the same side as the entry, P_i increases also, which results in the fact that $P_s - P_i$ remains approximately independent from X, although P_s and P_i are separately dependent on X (Fig.3*b*).

(ii) By ensuring that the difference $P_s - P_i$ is independent of X, $P_s - P_i$ being themselves separately independent of X.

If the general calculation of gas flows in regenerative chambers is considered, no longer assuming, as in the case of conventional construction, that height H of



a Simplified diagrammatic section of a regenerator profile
b Diagrammatic vertical section of a regenerator according to the new profile proposed

7 ***Theoretical research to improve gas flows in regenerative chambers of OH furnaces***

the roof above the checkerwork is constant, then it will be possible to derive a function $H(X)$ such that P_s is constant.

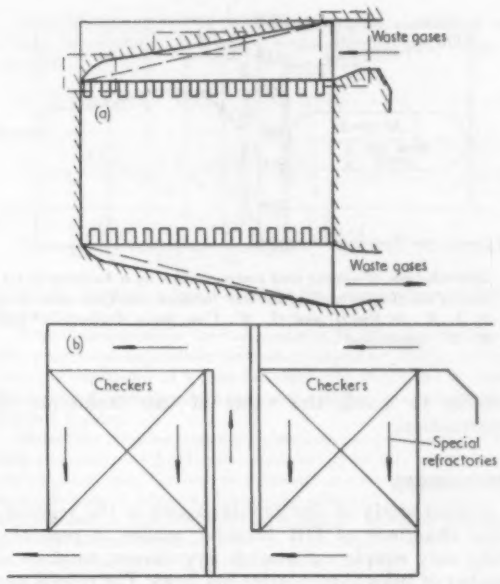
Calculation shows* that, to obtain this result, the horizontal speed V_h of the gases above (and under) the checkerwork must be independent of the passage section S between the roof and the checkerwork. That is to say that the height of the roof above the checkerwork should not be independent from X, but should be proportional at any point with the horizontal flow-rates of the gases circulating at this point of abscissa X.

Therefore, in practice, the height of the roof above the checkerwork should be defined by the relation:

$$H = H_o\left(1 - \frac{X}{L}\right)$$

Therefore, the roof of a regenerative chamber should slope in a linear way above the checkerwork, from the ingoing waste-gas opening, where its height should be maximum, to the wall opposite the slag-pockets, where the roof should come on a level with the checkerwork;† the symmetrical disposition should, of course, be adapted under checkerwork level, and the construction of the chamber should agree with the diagram Fig.7*a*.

Up to now we have assumed that the horizontal speeds of the gases V_h were constant above the checkerwork in any vertical 'slice' of abscissa X. This is merely a simplifying hypothesis; regularized speeds of the ingoing gases should largely contribute to improve the gas flows in regenerative chambers.‡[16] Several solutions to this problem may be contemplated; that which has the advantage of being simple, being to adapt a divergent profile,‖ dissymmetrical or



a Combination of two types of improvements
b Two pass regenerative chamber (aerodynamic profiles + inverted exit)

8 ***Types of furnace layout***

not, designed according to the irregularities which might have been detected through measurements, in the distribution of speeds at the entry of the regenerative chamber.§ The choice of the aerodynamic profile to adopt depends on the flow conditions above (the profile of the slag-pockets and of the uptakes), which determine the distribution of the speeds at the regenerator entry, and on the available locations.

Lastly, it is self-evident that all that has been said about the adaptation of a streamlined profile at the upper part of the regenerative chamber also applies to its lower part, where it will be an advantage to have the ingoing air speeds as uniform as possible.

All these changes might lead, for instance, to the adoption of a construction in agreement with the vertical section of Fig.7*b*, with a flat roof built of entirely suspended basic bricks.

It is to be noted that such a solution is not incompatible with the one indicated in item (i) and that a combination of both types of construction may be contemplated to advantage, according to a scheme outlined in Fig.8.

Another way of putting into practice this principle of convergence of the checkerwork on the one hand and of the hearth and roof on the other is indicated by the practical solution proposed by De Graaf and Van Stein Callenfells,[8] which is shown in Fig.9. This figure also shows that an experimental study has made it

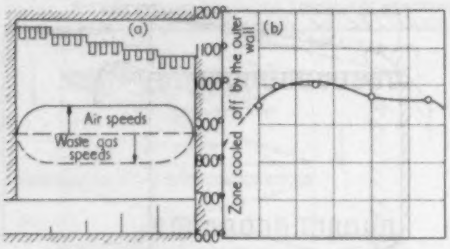
* *See* Appendix II.

† This solution, which is only schematic, does not rule out the possibility of a curved edge connecting the roof to the wall opposite the slag-pockets to improve the aerodynamic flow-conditions in the area near this wall.

‡ See item (ii) under 'Improvement of gas distribution in conventional regenerative chambers', p.217, also ref.16.

‖ The adoption of a divergent profile at the entry of the regenerator seems more desirable than that of a convergent profile, since a divergent profile makes it possible to increase the entry section to the regenerator 'S_o', hence to cut down the horizontal speed 'V_o' of the ingoing gases, which tends to regularize the gas-flows.

§ It is known that a divergent profile, dissymmetrical or not, alters the speed distribution curves, and as a dissymmetrical divergent profile may affect a symmetrical distribution of gas-speeds, it may also make it possible to regularize any non-symmetrical distribution of gas-speeds.



9 *Distribution of speeds and temperatures in a horizontal section of the checkerwork of an OH furnace, modified according to J. E. de Graaf and G. W. Van Stein Callenfels[8] and K. W. Dockhorn[9]*

possible to check the value of this technique of construction.

CONCLUSIONS

A general study of the aerodynamics of the regenerative chambers of OH furnaces makes it possible, using only simple calculation hypotheses, to draw a number of rules to regularize gas flows. The results are in full agreement with the experimental findings on regenerators of improved profile, with production furnaces as well as with small-scale models.

In general it should be possible to regularize gas flows by taking into account the following recommendations:

1. If it is not systematically sought to regularize the driving depressions, it will be of interest:
   - (i) to have speed conditions as regular and as low as possible above and under the regenerative chambers
   - (ii) to construct the highest and the shortest possible chambers
   - (iii) to have heavy head-losses through the checkers, either by resorting to multiple-pass construction (*see* Figs.4, 5, and 8*a*), or by reducing the section of the flues on the whole height of the checkerwork, or at least, in its upper part.*
2. If it is sought to regularize the driving depressions system, it will be possible to resort moreover to two types of solution:
   - (i) to locate the lower entry of the regenerator chamber under the upper one instead of in the opposed direction (Fig.6)
   - (ii) to make the roof and the hearth converge towards the checkerwork in accordance with one or other of the types of construction schematized by Figs.7 and 9.

It should also be noted that both types (i) and (ii) can be easily combined, e.g. in Fig.8*a*.

Thus, the steelmaker now has at his disposal a number of efficient means to improve the aerodynamics of his regenerative chambers. Possible progress, however, depends to a large extent on the conditions at the entry, especially during the waste-gas phase, since on the one hand the distribution of the speeds of the gases entering the chambers has an important bearing on the aerodynamic phenomena that take place there, and on the other hand the dust held in suspension in the waste gases dangerously erodes the checkers.† Therefore it is hoped that an effort will be made both by laboratory research workers and by steelmakers to improve the operation of the slag-pockets which, at present, leave much to be desired, and whose construction defects may hide the real improvements obtained with the regenerative chambers themselves.

APPENDIX I

Simplified calculation of the driving depressions and of the gas-flow conditions in the regenerative chambers‡

The essential conditions of the gas flow may be defined by the following notations:

- V_v vertical speed of the gases at the top of the checkers
- P_e pressure at the entry of the regenerative chamber
- V_e waste-gas speed, assumed to be uniform and horizontal at the regenerator entry
- H_e height of the roof above the checkers at the regenerator entry
- H height of the roof of the chamber above the checker at any point
- L length of the regenerative chamber
- X abscissa of point M counted from the bridgewall at the chamber entry
- P_s and P_i pressures at the top and bottom of regenerative chamber, in a point on the abscissa X‖
- T and K parameters already explained (second footnote, page 216)
- r specific weight of waste gas
- b ratio of the total surface of the flues to that of the total surface of the checkers in a horizontal section.

Neglecting the viscous friction of the gases against the walls, and applying the theorem of Bernouilli,§ we obtain:

$$\frac{P_s}{r} + \frac{V^2}{2g} = \frac{P_e}{r} + \frac{V_e^2}{2g} \quad \ldots\ldots(1)$$

but $V^2 = V_h^2$ if we are close enough to the roof for V_v to be negligible compared with V_h $\ldots\ldots(2)$

$$\text{hence: } P_s = P_e + \frac{r}{2g} V_e^2 - \frac{r}{2g} V_h^2 \quad \ldots\ldots(3)$$

The rates of flow through the checkers, and therefore the vertical speeds V_v, depend at each point M of abscissa X of the actual driving depressions:

$$P_m = P_s - P_i + T \quad \ldots\ldots(4)$$

* It will also be possible to resort to a closed-flue type of construction which offers the threefold advantage of increasing the brick–gas exchange areas, of increasing the weight of brick per unit of volume of checkers, and of decreasing the danger of clogging up.

† This aspect of the question is all the more important as the use of oxygen tends to originate and spread considerable quantities of dust which are borne by the waste gases.

‡ All calculations apply to the 'waste-gas' phase of the checkers' operation however, these conclusions also apply directly to the 'air' phase, since the gas-flow phenomena are symmetrical with those of the other phase.

‖ *Note:* Here we assume that pressures P_s and P_i are constant in the whole vertical 'slice' of abscissa X.

§ Which implies, of course, the hypothesis of a laminar and irrotational flow. However, the same results can be obtained, but in a less general way, without this hypothesis, by applying the Mariotte law alone, as will be seen later.

and we have, as first approximation:

$$V_v = \sqrt{K(P_s - P_i + T)} \quad \ldots\ldots(5)$$

Some additional definitions are now required:

Q_o total flow-rate of the waste gases

Q flow-rate of the waste gases having already entered the checkers at point of abscissa X

l checker width*

Then for the average value of V_{hm} of V_h in the 'slice' of abscissa X:

$$V_{hm} = \frac{Q_o - Q}{Hl} \quad \ldots\ldots(6)$$

but

$$Q_o = V_o H_o l = V_o S_o \quad \ldots\ldots(7)$$

and

$$Q = lb\int_O^X V_v\,dX \quad \ldots\ldots(8)$$

hence

$$V_{hm} = \frac{H_o V_o}{H} - \frac{b}{H}\int_O^X V_v\,dX \quad \ldots\ldots(9)$$

but V_h is connected to V_{hm} by a relation of the shape:

$$V_h = aV_{hm} \quad \ldots\ldots(10)$$

in which a is a parameter depending of function $V_h = V_h(z)$ defining the variation of V_h in the vertical plane of abscissa X. (If this variation were linear, neglecting the viscous frictions and knowing that $V_h(O)=O$, we would have $a=2$ close to the roof.

Combining equations (3) and (5) to eliminate P_s:

$$V_v^2 = K\left(P_o - P_i + T + \frac{r}{2g}V_o^2\right) - \frac{Kr}{2g}V_h^2 \quad \ldots\ldots(11)$$

Under these conditions,

$$A = P_o + \frac{r}{2g}V_o^2 - P_i + T \quad \ldots\ldots(12)$$

and to simplify it may be assumed that:

$$\frac{\partial}{\partial x}A = O \quad \ldots\ldots(13)$$

By differentiating equation (9), we may write:

$$\frac{dV_h}{a} = -\frac{b}{H_o}V_v\,dX \quad \ldots\ldots(14)$$

Combining equations (11–14), aV_h and X differential equation may be deduced:

$$K\left(A - \frac{rV_h^2}{2g}\right)dX^2 = \frac{H_o^2}{a^2}(dV_h^2)\,x\,\frac{1}{b^2} \quad \ldots\ldots(15)$$

This equation may be integrated by the method of undetermined coefficients α and β while effecting the change of variable:

$$V_h = \alpha \sin\left[\beta(L-X)\right] \quad \ldots\ldots(16)$$

hence

$$V_h = \sqrt{\frac{2gA}{r}}\sin\left[\frac{a}{H_o}\sqrt{\frac{Kr}{2g}}(L-X)\right] \quad \ldots\ldots(17)$$

and:

$$V_v = \sqrt{\frac{KA}{b}}\cos\left[\frac{a}{H_o}\sqrt{\frac{Kr}{2g}}(L-X)\right] \quad \ldots\ldots(18)$$

Thus the increasing function of X, that we propose to determine.

If now we introduce the variations of P_i (a generalization of the restrictive hypothesis defined by equation (13)), we find that the variations of V_v are increased thereby when X varies from O to L, and therefore that our conclusions are reinforced by this finding.

In fact, in the area under the checkers, in the vicinity of the slag-pockets (zone A of Fig.2*a*), there is only a low flow flat-rate of waste gases, and this flow-rate steadily increases when moving towards zone B following increasing values of X. Therefore, at the bottom of the chambers a regime of variable pressures prevails, which decreases when X increases, i.e. which vary in the reverse direction of the pressure at the top.

APPENDIX II

Equations (3) and (5)

$$P_s = P_o + \frac{r}{2g}V_o^2 - \frac{r}{2g}V_h^2 \quad \ldots\ldots(3)$$

$$V_v = \sqrt{K(P_s - P_i + T)} \quad \ldots\ldots(5)$$

As T, practically, does not vary,† for V_v remaining constant that is

$$\frac{\partial V_v}{\partial X} = O \quad \ldots\ldots(19)$$

it will be necessary to have:

$$\frac{\partial}{\partial X}(P_s - P_i = O \quad \ldots\ldots(20)$$

Equation (20) can be checked in two ways:

The first way implies that alone $(P_s - P_i)$ remain constant, although P_s and P_i vary separately, which corresponds to the solution proposed by Hansen and Luetscher.

The second implies that P_s and P_i are both independent from X. In the latter case, one should have:

$$\frac{\partial}{\partial X}P_s = O \quad \ldots\ldots(21)$$

The derivation of equation (3) defining P_s in relationship with X gives

$$\frac{\partial}{\partial X}P_s = -\frac{r}{g}V_h\frac{\partial}{\partial X}V_h \quad \ldots\ldots(22)$$

Therefore, for $\frac{\partial P_s}{\partial X} = O$, we should have:

$$\frac{\partial}{\partial X}V_h = O \quad \ldots\ldots(23)$$

the solution $V_h = O$ being, of course, only a particular case, without any practical interest.

Considering equation (9):

$$V_h = \frac{H_o V_o}{H} - \frac{b}{H}\int_O^X V_v\,dX$$

* The calculation assumes the roof to be flat, but it could be made for a curved roof. Then $S_o = \frac{3{\cdot}14}{2}H_o^2$ instead of $S_o = H_o l$, but the conclusions are unchanged.

† See Appendix III.

If equation (23) is verified, i.e. if V_s is independent from X and always equal to V_{sm}, we can write:

$$V_h = \frac{H_s V_s}{H} - \frac{bXV_{sm}}{H}$$

with $Q_s = V_{sm} L1b$ but, according to (7), we have then:

$$bV_{sm}L1 = V_s H_s l$$

hence:

$$V_{sm} = \frac{V_s H_s}{bL}$$

and:

$$V_h = \frac{H_s V_s}{H} - \frac{H_s V_s}{L}\frac{X}{H} \quad \text{.....(24)}$$

Then, let us determine, by means of a differential equation, functions $H(X)$ such that, whatever X be, equation (23) be verified. Through differentiation of (24) this equation is:

$$(L-X)\frac{dH}{dX} + H = O \quad \text{.....(25)}$$

The integration of this equation leads us to the general solution:

$$H = H_s\left(1 - \frac{X}{L}\right) \quad \text{.....(26)}$$

Note:

A demonstration of this result, simpler and almost intuitive, can be made, using only the Mariotte law. Let us call Q_m and Q_{m_s} the mass flow-rates of fluids at M and at the regenerative chambers entry, and let us suppose the problem solved. We have:

$$P_s = P_s \; V_h = \text{constant and } Q_m = Q_{m_s}\frac{L-X}{L}$$

On the other hand:

$$Q_m = lHrV_{hm} = P_s V_{hm} lHR_s$$

hence we should have:

$$P_s lR_s V_{hm} \times H = Q_{m_s}\frac{L-X}{L}$$

$$Q_{m_s}\frac{H}{H_s} = Q_{m_s}\frac{L-X}{L}$$

$$H = H_s\frac{L-X}{L}$$

APPENDIX III

Calculation of the weight T *of a vertical column of hot gases, having a section equal to the area unity, in regenerative chambers; perturbations by thermal dissymmetries that may exist in the checkers*

The weight of a vertical column of hot gases having a section equal to the area unity may be calculated by the formula:

$$T = \int_0^h R(z)dz \quad \text{.....(formula 1)}$$

in which $R(z)$ is the specific mass of the gas at a height z of the stack (the point $z=O$ corresponding to the bottom of the stack, and the point $z=h$, corresponding to the top of the latter).

Let us assume that the absolute temperature θ of the fluids is a linear function of z, and call θ_s and θ_i the fluid temperatures at the top and at the bottom of the checkerwork; we have:

$$\theta = \frac{\theta_s h + (\theta_s - \theta_i)z}{h}$$

we know that $R = \frac{273R_s}{\theta}$ (R_s = specific mass of the fluid at 0°C)

$$R = \frac{273R_s h}{\theta_s h + (\theta_s - \theta_i)z}$$

from which we deduce:

$$T = 273R_s h \int_0^h \frac{dz}{\theta_s h + (\theta_s - \theta_i)z}$$

Let us integrate the preceding expression:

$$T = \frac{273R_s h}{\theta_s - \theta_i}\log\frac{\theta_s}{\theta_i}$$

This formula shows that T, for a given fluid, is a variable depending both on θ_s and θ_i. Therefore if thermal dissymmetries exist in the checkers, we will have for instance in the case of waste gases, variations of θ_i according to the data considered.

However, these variations are low and may even be ignored in a first approximation. Effectively, let us consider as an example checkerwork where we would have:

$\theta_s = 1773°K$
$h = 4\ m$
$R_s = 1{\cdot}3$ kg/m³ (NTP)

If $\theta_i = 773°K$, we get: $T = 1{\cdot}18$ mm wg
If $\theta_i = 973°K$, we get: $T = 1{\cdot}065$ mm wg

or a variation of T lower than 0·1 mm wg depending on whether the exit temperature of the waste-gases is 500° or 700°C.

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Resistance to thermal stress fatigue of some steels, heat-resisting alloys, and cast irons

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SYNOPSIS

An outline is given of the results of thermal fatigue tests in which cracks were produced by repeated heating of one edge of a cold specimen. Fatigue life curves show the influence of the maximum and minimum temperatures in the cycle and emphasize the importance of the martensite transformation if it occurs in every cycle.

Comparative results are given for a number of different steels and for some heat-resisting alloys and cast irons. Factors influencing the thermal fatigue life, and the question of applying test results to service problems are discussed. 1905

THIS INVESTIGATION was started several years ago when there was an almost complete lack of published work on the subject and when in fact quite a number of people held that 'craze-cracks' could not be produced simply by the repeated application of thermal stress. Both the development of a laboratory test and the subsequent experimental work have been influenced to a large extent by practical problems arising in military equipment, but there was no intention to restrict the scope of the work to these applications. Details of the preliminary experiments have previously been described[1] and the present object is to summarize some of the later work.

The test involves repeated heating of one surface of a test piece, the main mass of which is continuously water cooled. The specimen is of truncated wedge form (Fig.1) and the narrow edge is heated giving uniaxial thermal stresses in the direction of the edge. The thermal expansion in the direction of the edge is not completely restrained, some 20% or 30% of the total expansion being lost, largely in bending of the specimen. The heating is by hf induction, the heating time being held between 1·0 and 1·3 s. The cooling time depends on the thermal conductivity and the minimum temperature required in the thermal cycle, and falls within the range 0·1–20 s. Temperatures are measured by fine-gauge thermocouple wires which are spot-welded to the surface and connected to a high-speed galvanometer, arranged so that part of the reflected beam operates photocells to give automatic control of the maximum and minimum temperatures in the cycle.

As a convenient criterion of failure in this specimen the numbers of cycles to produce cracks 0·020 in deep are measured, and cracks starting from thermocouple junctions are distinguished from the others in assessing the results. The important flat surfaces on the specimen are polished in the longitudinal direction before testing.

The test is rapid and has the advantage of giving numbers of cracks whose rate of growth can be continuously measured with a low-power microscope. The specimen is empirical in design but it simulates many of the conditions in which we are interested, and the type of thermal cycle obtained is one which is quite commonly found in various industries and branches of engineering.

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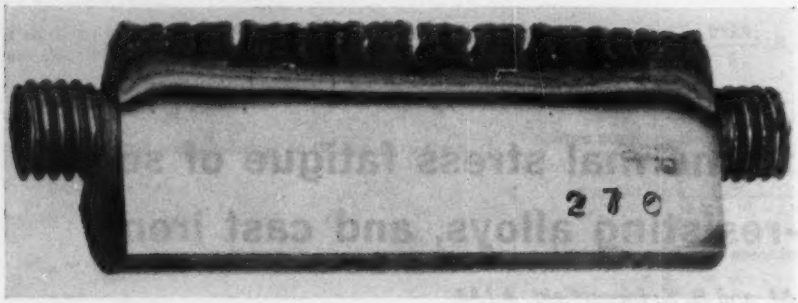
Influence of the temperature cycle

The fatigue life depends on the strain range per cycle and hence on the temperature range. In the previous paper the stress/strain cycles to be expected with various temperature cycles were considered in some detail. Experimentally it has been found that the fatigue life decreases rapidly when the maximum temperature in the cycle is increased, and the minimum temperature is held constant, although this is not always true in steels when the Ac_1 temperature is exceeded. Typical results are given in Fig.2 which shows the life of specimens of a 2½%Ni–Cr–Mo steel (details of which can be found in Table I; results with notched specimens may be ignored at this stage).

Conversely when the maximum temperature was held constant and the minimum temperature was increased the life also increased, but not as rapidly (Fig.3), i.e. it is better to reduce the peak temperature in the cycle than to increase the minimum temperature. This observation has been made and expressed in different ways in several contemporary investigations of thermal stress fatigue; it is probably associated with the decrease in strength which takes place when metals are heated, giving increased plastic strains when the mean temperature in the cycle is increased.

When the maximum temperature was high enough to produce austenite the effect of increasing the minimum temperature in the cycle was particularly curious. The rate of cooling in these tests was fast enough to produce martensite in most low-alloy steels and there was a marked discontinuity at the M_s temperature (300°C in Fig.4). Above 300°C the surface remained austenitic throughout the cycle and the life was increased in this case by a factor of eight. The type of cracking also changed.



1 *Steel test piece after 400 cycles, 40–850°C. (Normally the test would be stopped at an earlier stage of crack development)* ×2

Influence of phase changes

The repeated austenite–martensite–austenite cycle soon produces a characteristic rumpling of the surface (Fig.1). When sections were prepared through such surfaces and etched to reveal the 'fibre structure' it was found[1] that the valleys or necks in the corrugations had torn apart to give blunt-ended cracks, in complete contrast with the sharp cracks normally seen. Similar rumpling can easily be produced in viscous materials by reversed strain cycles in a thin surface layer, but in steels the rumpling only occurred when the thermal cycle included a phase change.

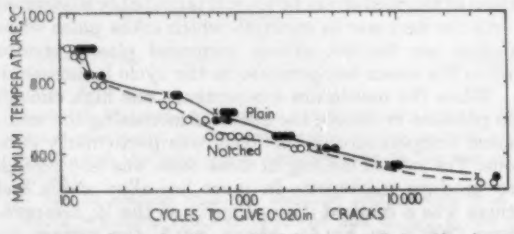
At first it was believed that the distortion was associated with the transformation to austenite on heating, which involves a contraction in volume large enough to put the surface into tension. However, in tests on several series of alloy steels it was found that additions of manganese, nickel, chromium, or molybdenum to a plain 0·35%C steel gave an increased tendency to this form of cracking, but separate additions of silicon, vanadium, or cobalt did not. Cobalt tends to decrease hardenability and, following this line of thought, the hardness of the surface of each test piece was measured. This revealed that rumpling was only pronounced in specimens where the heated surface had a Vickers hardness of more than 630, i.e. when the surface was almost completely martensitic (Fig.5). In contrast there was no correlation between the tendency to rumpling and the Ac_3 temperature or the associated volume change. It is concluded therefore that the rumpling is always associated with the martensite transformation, though there is some other evidence from tests on silicon steels that the converse does not always apply, i.e. the martensite transformation does not always produce rumpling. The mechanism of the rapid distortion and cracking produced during transformation is not known but it is presumably associated with the transformation induced strain which can occur at very small stress levels.[2]

Influence of stress concentration

When the temperature cycle is not very severe there is often a long induction period before any cracks appear, but if a small sharp notch is cut on the surface this period is almost eliminated (Fig.6). A single crack in a plain test piece grows at a similar rate, showing that the notch has no further effect once the crack is started. This property of a suitable notch is quite useful, since the rate of crack growth can be measured without reference to crack initiation and without interference from neighbouring cracks.

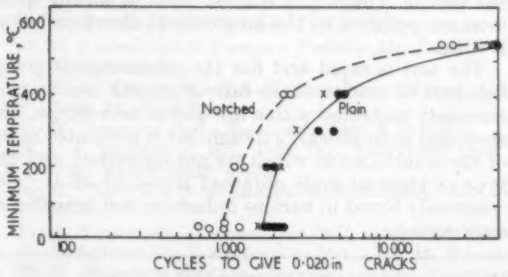
The influence of notch dimensions must of course be related to the size of the test piece and the depth of the heated zone. In this test piece, at a depth of 0·1 in beneath the surface, the peak temperature in the cycle fell to about half the surface temperature. A notch 0·05 in deep therefore penetrated through the most highly stressed layers, and the stress concentration at its root was less than that in shallower notches. A notch depth in the range 0·002–0·02 in had the most damaging effect, although scratches only 0·001 in deep greatly accelerated cracking (Fig.7). Notch radius had no significant effect when the notches were prepared by grinding, but this variable might be more important if a better surface finish could be obtained in the notch root. In general notches were less important when repeated phase changes were taking place.

A number of steels were tested using the cycle 40–600°C to find the comparative behaviour of plain and notched specimens. In general the ratio of the number of cycles to give 0·020 in cracks in the two types of specimen lay between 2·0 and 4·0 but two steels gave ratios of more than 5·0. One was a very brittle hypereutectoid steel which had a notched life of only 220

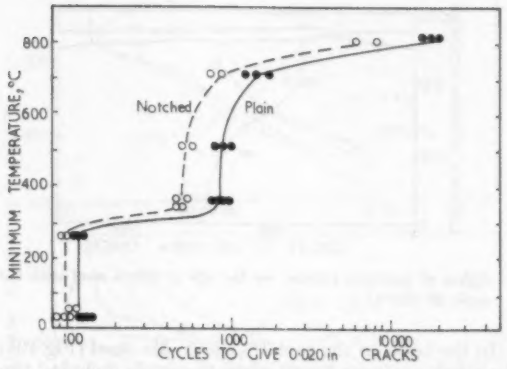


× = crack starting from welded thermocouple junction in unnotched specimen

2 *Effect of maximum temperature in the cycle on fatigue life. En25 steel. Minimum temperature in cycle 40°C*



3 *Effect of minimum temperature in the cycle on fatigue life, En25 steel. Maximum temperature in cycle 650°C*



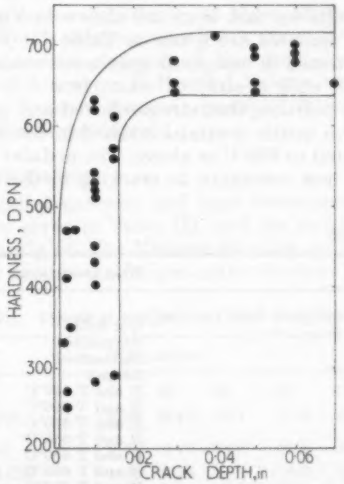
4 *Effect of minimum temperature in the cycle on fatigue life, En25 steel. Maximum temperature in cycle 900°C*

cycles. The other was a 3%Si–7%Cr valve steel which gave a notched life of 1490 cycles. The life of the notched test pieces depends primarily on the rate of crack growth and in this respect the Si–Cr steel was clearly much better than the hypereutectoid steel. The effect of different thermal cycles on the Si–Cr steel, notched and notch-free, is shown in Fig.8, for comparison with the more usual behaviour of steels shown in Fig.2.

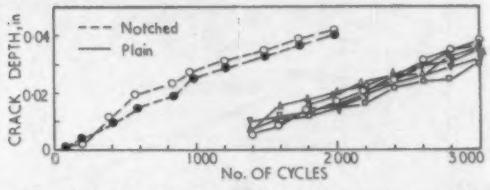
In these tests it has been repeatedly found that when the severity of the thermal cycle is reduced, crack initiation becomes more difficult than propagation and the number of cracks falls, eventually to one and then none at all. This observation has its counterpart in short-life fatigue tests when the strain range per cycle is reduced.

Interaction of cracks

With a severe temperature cycle large numbers of cracks may be initiated; each crack relieves the tensile strains for some distance, and as the cracks lengthen



5 *Relationship between martensite formation, as indicated by surface hardness, and crack depth. Points represent different steels containing 0·35%C. Cracks measured after 400 cycles, 40–850°C*



6 *Rates of crack growth in notched and plain specimens of En25 steel with the cycle 40–650°C*

they begin to reduce the rate of growth in their neighbours. Under these conditions some cracks eventually become dormant and others dominant, but the overall rate of growth is less than that of an isolated crack. Similarly it was found that multiple notches had less effect than a single notch provided the spacing between notches was less than about 0·08 in (Fig.9). The critical separation must of course depend on the temperature gradient, and it would decrease with a steeper gradient.

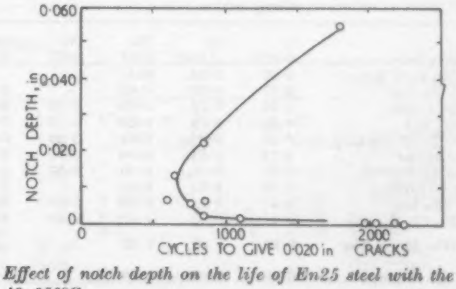
The experimental results with multiple notches are consistent with photoelastic work by Durelli *et al.*[3] on the stress concentration in flat tensile test pieces. They found that when one edge notch was machined near to another the stress concentration was reduced, and a series of at least five notches was needed to produce the greatest possible reduction in stress concentration. When the distance between notches was increased the stress concentration at the central notches increased until, when the distance was ten times the notch depth, the interaction had virtually ceased.

COMPARATIVE BEHAVIOUR OF DIFFERENT ALLOYS

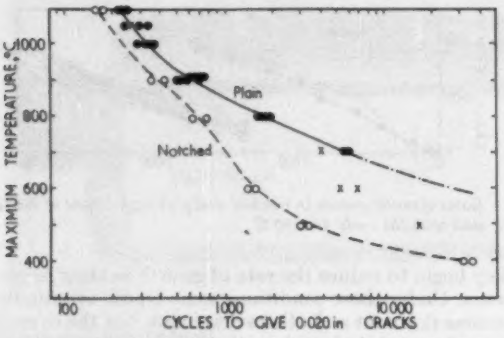
In view of the lack of information about the behaviour of different materials in thermal stress fatigue, opportunities have been taken to test the influence of the peak cyclic temperature on the life of various alloys and these results are summarized below.

Steels

Fatigue life curves for soft iron and several simple steels are shown in Fig.10*a*, and results for some stronger ferritic steels are shown in Fig.10*b*. The compositions, heat treatments, and hardnesses of these steels are given in Table I. The differences in life between the soft iron and the plain carbon steels was remarkably small, and the normalized steam-piping steels (½%Mo and 1%Cr–Mo) gave much better resistance to cracking.

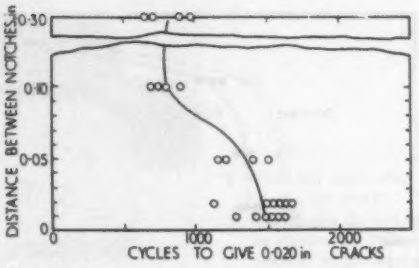


7 *Effect of notch depth on the life of En25 steel with the cycle 40–650°C*



× = crack starting from welded thermocouple junction in unnotched specimen

8 *Effect of maximum temperature in the cycle on fatigue life, 3%Si–Cr steel. Minimum temperature in each cycle 40°C*



9 *Effect of multiple notches on the life of En25 steel with the cycle 40–650°C*

Amongst the stronger and slightly more complex alloys shown in Fig.10*b* there is a noticeable trend for the alloys with the greatest hardness to give the best life when the peak temperature in the cycle is low. All the alloys in this graph had been hardened and tempered, and it should be remembered that the hardness quoted is of little significance when the peak temperature in the cycle exceeded the tempering temperature. Most of the alloys had been tempered at about 650°C and in this group the room temperature hardness is probably related to the hot strength (at temperatures up to 650°C) as well as to the room temperature strength. The amount of plastic strain in the cycle is dependent on the strength at both the minimum and maximum temperatures in the cycle,[1] other factors being equal, and the apparent correlation between hardness and life in this group of steels thus agrees with Coffin's finding[4] that the life in high-strain fatigue is largely dependent on the plastic strain per cycle.

As a corollary to this observation it is noticeable in the results that the alloys based on additions of chromium, tungsten, or other elements conferring hot strength tended to give greater resistance to cracking (at temperatures up to about 700°C) than the alloys based primarily on additions of nickel.

The hardness of the normalized steels in Fig.10*a* is not necessarily related to hot strength and in fact the steam piping steels gave better resistance to cracking at temperatures up to 700°C than their low hardness would suggest.

In the tests on the cast 3%Ni–Cr–Mo steel (Fig.10*b*) the crack patterns found when the cycle included the phase change suggested that the cracks were related to the cast structure, and this was confirmed when specimens were sectioned (Fig.11). Earlier work on steel bar had indicated that the direction of mechanical working in relation to the axis of the test piece could influence the rate of cracking, and to investigate this factor more thoroughly, two series of specimens were machined from a forging of 3%Cr–Mo steel with their axes respectively parallel and perpendicular to the direction of forging. The forging reduction applied to this material was probably about 5:1 in terms of the cross-sectional area of the ingot and the finished forging. However, no significant differences in life were found between the two series of specimens at any part of the curve.

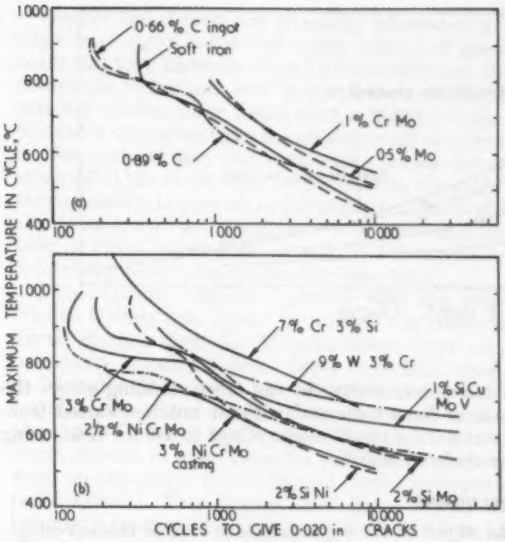
It is evident that the direction of working is not necessarily an important variable, but when, as in the earlier tests, the forging or rolling reduction is large and the thermal cycle includes a phase change it can be significant. It would probably be important also in long life tests at relatively low temperatures, by analogy with the well-known directional effect found in conventional fatigue testing.

Cast irons

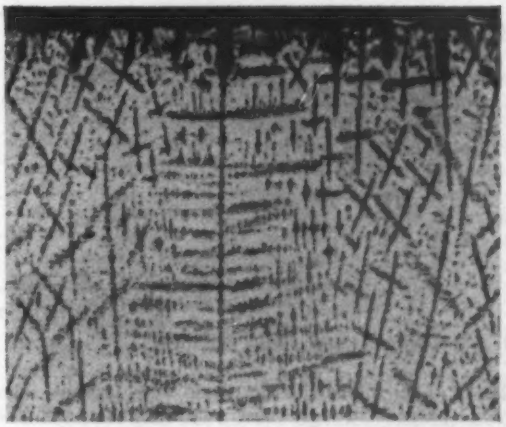
Some results on cast irons are shown in Fig.12, and chemical analyses are given in Table II. The white iron was tested in composite specimens made up of a steel base with a strip of white iron 0·2 in deep, brazed in position, then stress-relieved and ground to shape. This brittle material cracked in the first cycle when heated to 650°C or above. The nodular cast iron gave the best resistance to cracking in this group of

TABLE I Chemical analysis, heat treatment, and hardness of the steels used

Type	Composition									Heat treatment	Hardness
	C	Si	Mn	Ni	Cr	Mo					HV/30
Soft iron bar	0·021	<0·01	0·01	0·07	0·02	0·06				Hot rolled	95
0·5%Mo steel bar	0·10	0·25	0·47	...	...	0·55				Normalized	145
1%Cr–Mo bar	0·07	0·46	0·43	...	0·84	0·55				Normalized	155
0·66%C ingot	0·66	0·28	0·69	0·06	0·06	<0·01				As-cast	225
0·89%C bar	0·89	0·32	0·28	0·07	0·09	0·06				H and T 650°C	235
3%Ni–Cr–Mo casting	0·33	0·27	0·62	3·00	0·66	0·49				H and T 660°C	275
2%Si–Ni bar	0·32	2·14	0·56	2·13	0·08	...				H and T 650°C	280
3%Cr–Mo forging	0·31	0·18	0·58	0·35	3·30	0·53				H and T 650°C	305
7%Cr–Si forging	0·48	2·91	0·55	...	6·98	0·56				H and T 850°C	310
2%Si–Mo bar	0·41	2·12	0·29	0·06	0·29	0·75				H and T 650°C	380
2·5%Ni–Cr–Mo bar	0·31	0·19	0·72	2·68	0·72	0·42				H and T 550°C	395
1%Si–Cu–Mo–V bar	0·29	1·13	0·22	...	...	0·78	V 0·29	Cu 1·75		H and T 600°C	495
9%W–Cr forging	0·39	0·36	0·39	...	3·4	0·10	W 9·20	V 0·34	Nb 0·22	H and T 640°C	570



10 *Superimposed fatigue curves, steels*



11 *Cracks in a specimen of centrifugally cast En25 steel, hardened and tempered and given 400 cycles, 40–750°C. Etched in Oberhoffer's reagent* ×10

materials, but as might be expected its resistance was somewhat inferior to that of the steels. The cracks tended to travel through the nodules of graphite but in places the cracks found interdendritic weakness (Fig.13).

The nodular iron was tested in two conditions, and in the higher temperature tests the more ductile ferritic form gave the better results, but the pearlitic as-cast iron was perhaps slightly better at lower temperatures (Fig.12). This agrees with the observation which has been made by Forrest[5] on the change-over in the relative importance of strength and ductility when the strain amplitude is increased in thermal fatigue tests. Similar observations have been made in constant-strain fatigue tests.

The grey iron was a pearlitic 'engineering' iron with a fine graphite structure. Its thermal fatigue properties were markedly inferior to those of the nodular iron, except at temperatures below about 500°C where the compressive strength of the grey iron became useful (in this type of thermal fatigue test, plastic strain in compression is necessary before tensile stresses can be produced).

Heat-resisting alloys

The chemical analyses and heat treatments of these alloys are given in Table III, and the test results are shown in Fig.14. The Nimonic 90 alloy showed a pronounced knee in the fatigue curve at about 950°C and it was found that at this temperature recrystallization started and the mode of cracking became predominantly intergranular. The new crystals tended to nucleate near existing grain boundaries (Fig.15) and the reasonable inference is that recrystallization in severely worked regions retards crack development.

In Nimonic 100 the various stages of recrystallization took place at higher temperatures, perhaps 50°C above the corresponding stages in Nimonic 90. Oxidation was rather heavy in Nimonic 100 with the cycle 40–1050°C. In both of these alloys there was a gradual trend towards intergranular fracture with increasing temperature (the development of holes at the grain boundaries can be seen in the lower part of Fig.15). The transition to this type of failure, which is usually associated with creep, is shown clearly in Fig.16, which is a photograph of the surface of a specimen from another batch of Nimonic 90 after cycling between 40° and 900°C. The cracks can be seen to develop both at the grain boundaries and along slip lines.

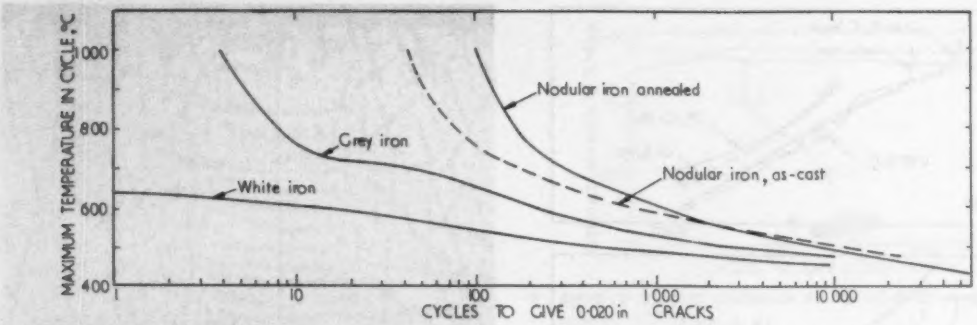
In the cast G39 alloy there was an almost continuous network of interdendritic eutectic along which the cracks travelled (Fig.17) without reference to the primary grain boundaries. In the cast X40 alloy small

TABLE II Chemical analysis, cast irons

Type	Composition								
	C total	C combined	Si	Mn	S	P	Ni	Cr	Mo
Grey	3·23	0·71	1·44	0·79	0·091	0·44	0·50	0·05	0·10
White	3·87	...	0·18	0·16	...	...	0·06	0·04	0
Nodular	3·07	0·50	2·11	0·26	0·009	0·037	1·05	0·01	0

TABLE III Chemical analysis and heat treatment, heat-resisting alloys

Type	Composition												Heat treatment
	C	Si	Ni	Cr	Co	W	Mo	Ti	Nb	Al	Ta	Fe	
Nimonic 100	0·23	0·36	57·5	11·3	19·5	0·11	4·7	1·35	...	4·40	...	0·44	1½ h at 1200°C AC 16 h at 850°C AC
Nimonic 90	0·08	0·77	58·0	19·6	16·4	0·01	0·08	2·66	...	1·09	...	0·67	8 h at 1080°C AC 16 h at 700°C AC
Jessop's G42B	0·25	0·34	15·4	19·2	25·2	2·70	3·00	1·00	0·30	0·07	...	32·50	Warm worked
Jessop's G39	0·50	1·1	46·5	21·1	...	3·50	2·60	...	0·79	...	0·66	23·10	As-cast
Stellite X40	0·47	0·53	10·9	24·5	54·0	7·20	1·40	...	0·04	...	0·24	1·10	As-cast
19–9 Stainless	0·10	0·77	9·2	18·7	...	...	0·03	0·72	...	...	...	...	Annealed
19% Chromium iron	0·09	0·58	0·66	19·3	...	...	0·41	0·24	...	...	...	...	Hot rolled

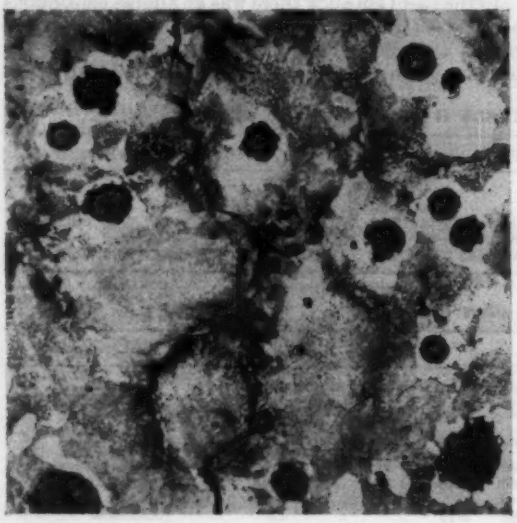


12 *Superimposed fatigue curves, cast irons*

islands of an interdendritic phase were present. The cracks passed through these islands, but there was occasional evidence of cracks travelling along the grain boundaries between dendrites. However, the overall impression was that the poorer resistance to thermal fatigue of these cast alloys was attributable more to their heterogeneity than to their very large grain size.

Also shown in Fig.14 are the results obtained with an austenitic stainless steel and a ferritic steel, each containing 19%Cr. These materials have no pretensions to creep strength but they gave remarkably good resistance to cracking with high temperature cycles such as 40–1000°C. However, the austenitic steel was much more notch sensitive than the other, a notch reduced the life by a factor of 5 with the cycle 40–950°C. The ferritic 19%Cr steel, on the other hand, showed considerable disturbance of the surface along planes of shear when the peak temperature exceeded 750°C, and crack development occurred along the same planes (Fig.18). Rather similar behaviour was found in tests on the silicon–chromium valve steel, which also showed low notch-sensitivity in the high temperature tests (Fig.8) where this type of shear failure occurred.

The crack starting from the thermocouple weld in the test piece of X40 shown in Fig.18*b* is an indication of notch-sensitivity. In the creep-resisting alloys the ratio of lives with and without notches varied from about 3·0 for the Nimonic alloys to 4·5 for X40, using the cycle 40–950°C.



13 *Crack path in a nodular cast iron* ×200

DISCUSSION

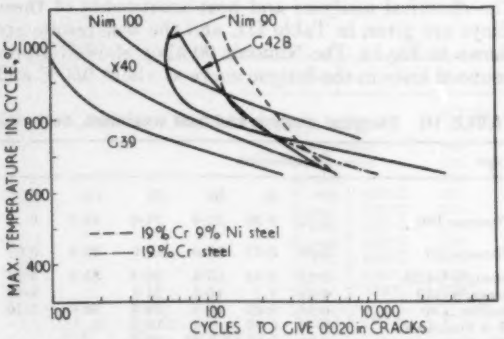
The object of the discussion is to look at this investigation in relation to some of the other work on the subject, and to outline some important factors which must be considered in any assessment of a particular thermal fatigue problem.

The thermal conditions which commonly lead to cracking can be broadly classified into four types:

(i) local heating, interior or restraining member remains cold
(ii) local heating, interior or restraining member eventually attains or approaches the surface temperature
(iii) local quenching, interior remains hot
(iv) local quenching, interior eventually cools to the surface temperature.

Somewhat idealized stress–strain cycles resulting from thermal cycles of types (i) and (iii) have been given by Northcott and Baron,[1] and examples of types (ii) and (iv) have been given by Glenny and Taylor.[6]

Our interest is mainly in the type (i) cycle but the stress–strain–temperature cycle produced by (i) is closely related to that given by (iii) provided the same restraint is obtained and the strains are large.[1] However, (ii) and (iv) are fundamentally different because of the gradual change in temperature and length of the restraining mass, which produces a corresponding change in stress in the surface element.



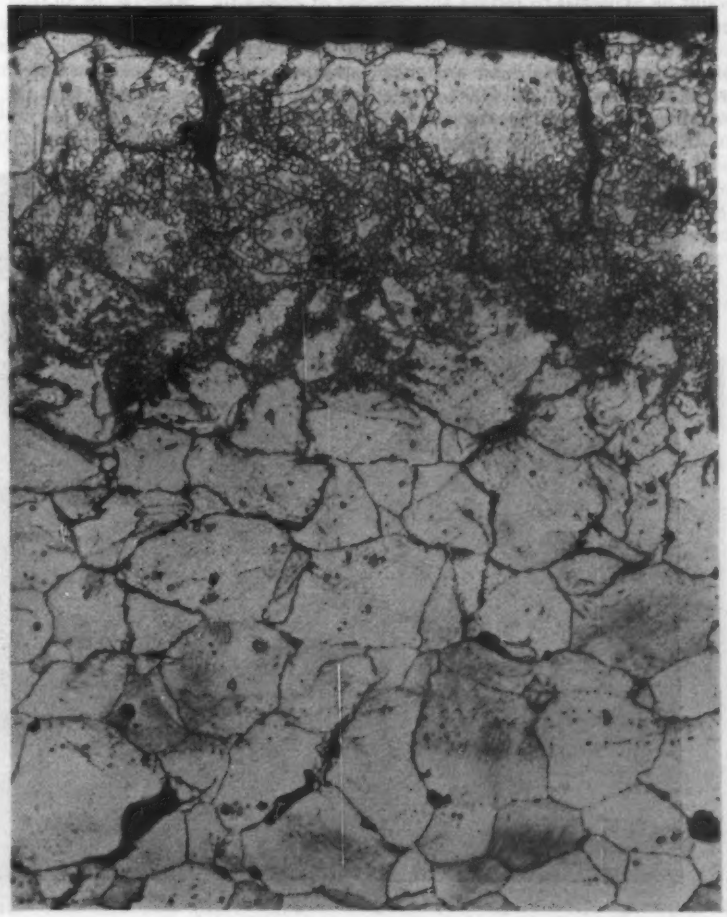
14 *Superimposed fatigue curves, heat-resisting alloys*

Glenny and Taylor are primarily interested in the edge cracking of rotor and stator blades of gas turbines and they have developed a simulative test which makes use of hot and cold fluidized beds as the heat-transfer media. They found that a heating cycle (ii) was more damaging than the cooling cycle (iv) because in the former case the maximum tensile stress is attained at the maximum temperature in the cycle. At the maximum temperature the yield strength is generally at its lowest point and there is an increased likelihood of creep-type failure, especially if the specimen is held at the peak temperature for some time.

This explains why, in contrast with the present results, Glenny and Taylor found that the cracks produced in their tests on Nimonic alloys were almost invariably intercrystalline. Intercrystalline cracking in Nimonic 90 and 100 was obtained in the present experiments when the peak temperature exceeded about 900°C, but it has not been seen in the work on steels (except in some experiments where the surfaces were deliberately contaminated with low-melting-point metals). This implies that slip is easier than boundary movement in the conditions of these tests on steels, since the creep type of intercrystalline fracture is associated with boundary flow. However, when repeated phase changes take place the gradual build-up of voids at grain boundaries is clearly not possible.

Rädeker[7] has carried out thermal fatigue tests on thick cylinders of steel, and some of his results appear at first sight to be at variance with other work. The cylinders were slowly heated in a furnace and then quenched by the passage of a limited quantity of water along the bore, the cycle lying somewhere between types (iii) and (iv). Cracks developed rapidly in several steels when quenched from 400°C, but increasing the quenching temperature in 100° increments to 700°C produced increasing distortion of the specimens and the number of cracks produced passed through a maximum, though the crack depths tended to show a continuous increase. Low alloy steels are very weak at temperatures over about 500°C, and the severe distortion of the outside of the cylinders shows that the strength was too low to restrain effectively the contraction of the bore on cooling. This would seem to be an inherent difficulty in repeated quenching tests (unless the test piece is in the form of a solid sphere which is uniformly quenched).

Rädeker[8] later carried out some rapid heating tests and found it comparatively difficult to produce cracks. However, there were many incidental differences

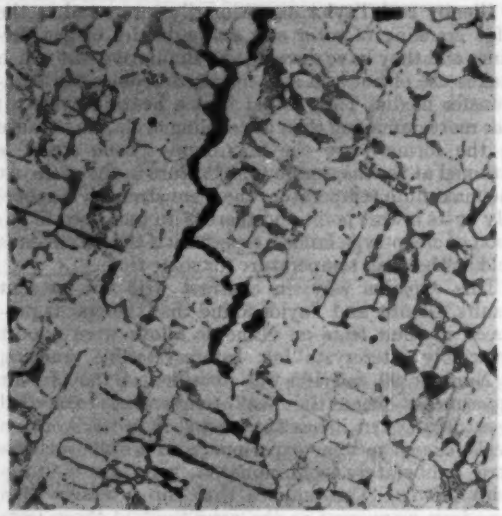


15 *Section through a specimen of Nimonic 90 after 800 cycles, 40–950°C* ×150

between the two tests and it would be unwise to draw general conclusions from the comparison.

When engineering design data are required the push-pull type of thermal fatigue test, first designed by Coffin,[9] can be particularly useful. The thermal stress can be measured and the degree of restraint of the test piece is capable of adjustment, although in its usual form this test gives some strain concentration at the centre owing to the variation of temperature along the gauge length. Coffin's relationship $N^{\frac{1}{2}}\Delta\epsilon_p=C$, where N is the number of cycles to failure and $\Delta\epsilon_p$ is the plastic strain range per cycle, is also useful in design. This relationship has wide application to high-strain fatigue results at constant temperature, but its application to thermal stress fatigue must be more restricted because the implicit assumption that details of the strain/temperature relationship do not matter, can only apply over limited ranges of temperature.

At temperatures where rapid creep can occur the time factor may be important. The rates of heating and cooling in the present tests are quite fast, and because of the time required for conduction, they could not be greatly increased unless even thinner surface layers were investigated. Much longer soaking periods at or near to the peak temperature are sometimes encountered in practice, e.g. in ingot moulds and gas turbine blades, and any creep during this interval would be expected to reduce the number of cycles to give cracking. A rather uncertain trend towards such a reduction in life was noted by Coffin[9] in thermal fatigue tests on an 18–10 austenitic stainless steel, cycled between 200° and 500°C, but it is probable that the time factor could be more critical under other conditions.



17 *Crack path in G39 alloy* ×100

Laboratory tests for thermal fatigue produce a stress system which is in most instances uniaxial, whereas in service the system is frequently biaxial, with considerably enhanced strains as a result of the Poisson's ratio effect. A numerical example for a type (i) cycle illustrates the importance of this effect; it was estimated[1] that the yield stress would be attained in a given steel on first heating to 390°C with uniaxial restraint, or to 280°C with biaxial restraint; and to

16 *Surface of a specimen of Nimonic 90 after 800 cycles, 40–900°C* ×150

produce repeated plastic strain in subsequent cycles the peak temperatures required in the two stress systems would be 630° and 520°C respectively.

Another factor to be considered is the thermal conductivity; a high conductivity is often useful in service because it helps to reduce temperature differences and thermal stresses. This was illustrated in the investigation by Lardge[10] when he compared the life of homogenous sheet of heat-resisting alloys with that of similar alloys clad on copper. Under the conditions of flame heating which he used, the clad materials gave much better lives. In the present test the thermal conductivity should have little or no effect on the results since the temperature gradient is imposed on the specimen; materials of higher conductivity simply requiring a higher power input to produce the required peak temperature and a shorter cooling time to reach the required minimum temperature. (In practice, metals having good thermal and electrical conductivity cannot be heated sufficiently to enable them to be tested with the present equipment.)

The influence of oxidizing and other atmospheres on thermal fatigue cracking is a matter requiring further investigation. Little has been published on this subject but it is known that Nimonic alloys give appreciably longer lives when tested in an argon atmosphere,[6] and that a hydrogen atmosphere can alter the direction of cracking in a structural steel towards the planes of maximum shear stress.[1]

CONCLUSIONS

In tests where uniaxial thermal stresses were produced by repeated heating of one edge of a specimen, the main mass of which was not allowed to get hot, it was found that:

1. In general the alloys with the greatest hot strength give the greatest resistance to cracking, provided that the strains are not too large (and the comparison is made between alloys of similar Young's modulus and coefficient of expansion).

2. When the thermal strains are increased it appears, as Forrest has suggested, that ductility becomes more important than strength.

3. In steels, any phase changes during the thermal cycle should be avoided if possible, particularly the martensite transformation which rapidly gives rise to deep blunt-ended cracks.

4. An annealing effect at the peak temperature may be helpful, as indicated by the improvement in life of Nimonic 90 when the peak temperature was high enough to allow recrystallization.

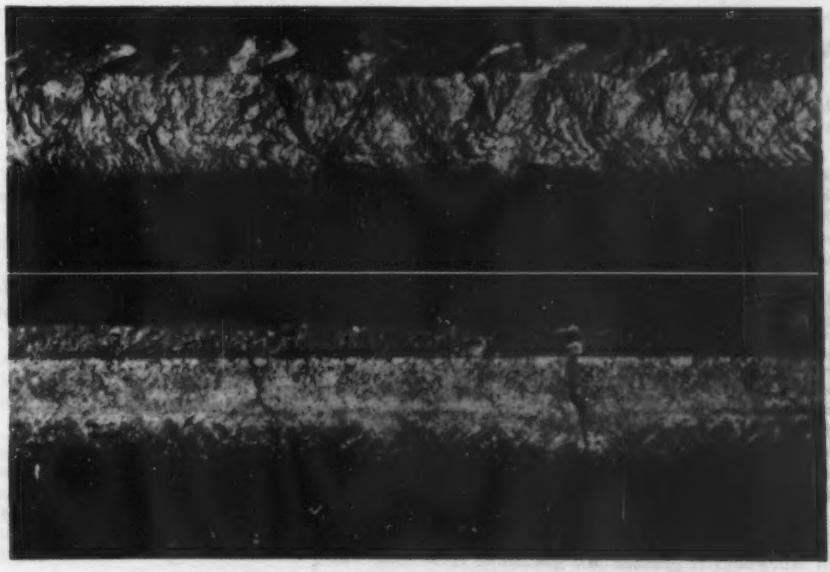
5. In steels the cracks were usually fairly straight, with no relation between the crack path and the grain structure. In Nimonic 90 and 100 there was a gradual change from crack initiation on slip planes to cracking at grain boundaries when the peak temperature in the cycle was increased.

6. Two heat-resisting alloys in the cast condition showed thermal fatigue cracks which travelled through interdendritic constituents. This suggests that the relatively poor behaviour of these alloys compared with the wrought heat-resisting alloys may be attributed to their heterogeneity.

7. The angle between the axis of the test piece and the direction of working had no detectable effect on the rate of cracking in specimens cut from a Cr–Mo steel forging. However, earlier tests on bar showed that a directional effect can be found when the amount of reduction in hot working has been large.

8. Brittleness at high temperatures is not expected to affect the life because the surface is then in compression. (In contrast, the thermal conditions used by Glenny and Taylor are capable of producing tension at the peak temperature, and a tendency to hot-shortness may then seriously reduce the life.[6])

9. Since tension can build up to a high stress level during cooling, it would be expected in the present tests that brittleness at the minimum temperature in the cycle would lead to rapid cracking. Such behaviour has been found in some varieties of cast iron and in one of the steels (a 1·2%C steel). Some of the other steels which have high fracture–transition temperatures



a 19% chromium iron after 610 cycles 40–1 050°C

b G42B alloy after 520 cycles 40–1 050°C

18 *Cracks developing along shear planes* (a) *where strain is concentrated, in comparison with* (b) *a more common type of cracking* ×10

might well crack more readily in large components than they do in these small test pieces.

10. A greater improvement in life can be obtained by reducing the peak temperature in the cycle than by a corresponding increase in the minimum temperature; but alloys which are brittle at low temperatures may provide an exception to this rule.

11. The effect of a sharp notch in the surface is to initiate cracking at or near to the beginning of thermal cycling, thereafter the rate of growth of the crack is not greatly affected by the notch.

12. Notch depth is not very critical, since depths of 0·002–0·020 in appeared to be equally effective. However, a very deep notch which penetrates the heated layer provides local stress relief and retards or inhibits cracking.

13. Multiple notches have less effect on the initial rate of crack growth than a single notch, provided that the spacing between notches is less than some critical distance. Similarly, adjacent cracks propagate less rapidly than an isolated crack.

14. When the peak temperature in the thermal cycle is reduced, a stage is eventually reached where crack initiation becomes more difficult than propagation and the numbers of cracks decrease. In general, notch sensitivity would be expected to be at its greatest at this stage, and the results tend to confirm this.

15. None of the alloys tested could be said to be the best under all the conditions used. With peak temperatures in the range 850–1050°C an austenitic stainless steel and a 19%Cr iron gave the best lives. Of these two alloys the austenitic steel showed less surface distortion but was much more notch sensitive.

When the peak temperature was below 800°C, Nimonic 100 gave the longest life, followed by a Si–Cr valve steel which was overtaken below 700°C by a W–Cr die steel and Nimonic 90.

16. Good examples of nodular cast iron approached the plain carbon steels in resistance to cracking. With high peak temperatures nodular iron gave its best life when in the annealed (ferritic) condition. The as-cast (pearlitic) condition tended to be slightly better at lower temperatures.

A sample of white cast iron broke in the first cycle of 20–600°C but withstood a mild cycle such as 40–400°C. A grey engineering cast iron provided intermediate behaviour between the white and nodular irons.

17. The results of these thermal fatigue tests cannot in general be applied to service conditions where the time–temperature–strain cycle is considerably different. The degree of restraint requires special attention and also the direction of restraint. Restraint in two directions results in biaxial stresses and increased strains compared with a uniaxial system. Another vital factor is the type of thermal cycle (*see* conclusion 8); there are four basic types and important differences exist in the temperature–strain sequence.

ACKNOWLEDGMENTS

The authors are grateful to Dr L. Northcott for his interest and to Capt. P. T. Aldridge for some of the experimental work.

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New Special Reports

The latest volumes to be published in the Institute's Special Report Series are the proceedings of two symposia held in London in May 1960.

Special Report 67 'Production of wide steel strip' reports the symposium on wide strip which formed part of the Institute's Annual General Meeting in 1960. The papers, from Italy, the Netherlands, the UK, and the USA, are divided into five groups, dealing with future requirements of user industries, steelmaking for wide strip, hot rolling, cold rolling and heat treatment, and coatings respectively. They are printed in full, together with a report of the lively discussions at the meeting. There is a foreword from the President, Mr W. F. Cartwright, D.L., J.P.

This report is a quarto volume of 196 pages, printed on imitation art paper and illustrated with 98 line diagrams and 57 photographs. Copies may be obtained, price £3 5*s* 0*d* each (postage 1*s*) from the Secretary.

Special Report 68 'The determination of gases in metals' is a report of the symposium organized last May by the Society for Analytical Chemistry in conjunction with The Iron and Steel Institute and The Institute of Metals. This highly successful joint meeting was based on a series of papers dealing with the latest developments in the methods of gas determination in both ferrous and non-ferrous metals, including vacuum fusion, carrier-gas methods, activation analysis, emission spectrometry, isotope dilution, and internal friction methods. There are also excellent review papers on the three main gases, oxygen, hydrogen, and nitrogen. As with the wide strip proceedings, there is a full report of the discussions at the meeting.

Octavo format has been used for this volume, which comprises 316 pages and 8 plates; it is amply illustrated with line diagrams, and provided with an attractive dust jacket. Copies may be obtained, price £3 3*s* 0*d* each (postage 1*s*) from the Secretary.

The spread of molten tin on mild steel reduced in hydrogen or treated with molten fluxes

E. T. Turkdogan and Miss Susan Zador

SYNOPSIS

It had always been assumed that the presence of an iron oxide film on the surface of the strip was the main deterrent to the tinning of steel. To study the effect of the removal of this film, steel strips were subjected to reduction for various lengths of time, at different temperatures, in dry hydrogen or hydrogen–argon atmosphere and then tinned. The effects of wet reducing atmospheres, of surface roughness, and of hydrogen chloride gas were also investigated. In none of these cases was the spread of tin on the steel strip satisfactory. Tinning was then carried out using conventional inorganic fluxes, containing various amounts of stannous chloride, with and without previous reduction of the strip in a hydrogen–argon atmosphere. The results showed considerable improvement of spreading with zinc-chloride–stannous-chloride flux, and the inference was made that in addition to removing the oxide layer more efficiently from the surface of the steel strip, liquid fluxes also bring about the formation of intermetallic compounds necessary for better spreading. Some emf measurements were taken on iron/molten-flux/tin galvanic cells to obtain information on possible electrochemical reactions in the mechanism of tinning, and an attempt is made in the paper to explain the reactions that occur during the tinning operation in the presence of fluxes. It is concluded that the use of molten fluxes for tinning gives far better 'wetting' than can be achieved by gaseous reduction of the strip at high temperatures before tinning. 1878

INTRODUCTION

ALTHOUGH TINNING of mild steel has been practised for a long time, few basic studies on the mechanism of the process have been carried out. Reference should be made, however, to the work of Bailey and Watkins[1] who studied some of the aspects of the spread of tin and solder on a number of metals in a reducing atmosphere.

The present work was aimed at studying the spread of tin on mild steel reduced in dry or wet hydrogen or treated with molten fluxes.

EXPERIMENTAL

In these experiments cold-drawn steel strips were reduced at temperatures within the range 650–900°C and a small amount of tin was allowed to spread on the strips at temperatures 275–650°C for various lengths of time, and after cooling, the area of spread of tin was measured. The reduction and tinning operations were carried out in the same apparatus without contaminating the surface after reduction in hydrogen.

The apparatus used is shown schematically in Fig.1. A recrystallized alumina reaction tube, 1½ in dia. and 36 in long, was surrounded by two resistance furnaces along its length whose temperatures were controlled separately. Reduction was effected in one furnace, tinning in the other. With the arrangement shown in Fig.1, it was possible to move the strip, pulled by a silica hook, through both the furnaces without contaminating the furnace atmosphere with air. The tin was contained in a samll pyrex spoon with a long handle (*see* Fig.1) attached to a ground glass stopper. By turning this stopper, it was possible to place the tin on the strip without removing the sample from the furnace atmosphere.

The general experimental procedure was as follows: A degreased steel strip was connected to the silica hook and placed into the cold part of the apparatus; the glass spoon, holding 0·075 g tin, was put in position and the system was swept with hydrogen for 10–30 min. The strip was then pushed into the reducing furnace in an atmosphere of oxygen-free, dry argon and allowed 2 min to attain the reduction temperature of 750°C. The strip was then reduced, usually for 2 min in hydrogen or hydrogen/argon mixtures used either wet or dry, at a flow rate of 400 ml/min; in some experiments argon alone was used as it was expected that with pure argon passing over the heated strip, some release of the chemically and physically absorbed oxygen, would occur. The sample was then withdrawn to the tinning furnace and cooled in an argon atmosphere and, after attaining the tinning temperature in

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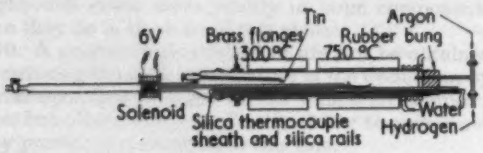


1 *Apparatus*

2·5 min, the argon atmosphere was replaced by the reducing atmosphere and tin released on to the strip. The tinned sample was then moved slowly to the cold part of the apparatus, allowed to cool in the reducing atmosphere for 1 min, the gas stream was then switched to argon for 2 min and the strip removed from the furnace. The tinning time was usually 5 s, except when otherwise stated. The tinned areas so produced were usually circular and the diameter was determined by taking the mean of four readings measured by a travelling microscope. When the area was irregular, the average of six or more measurements was taken.

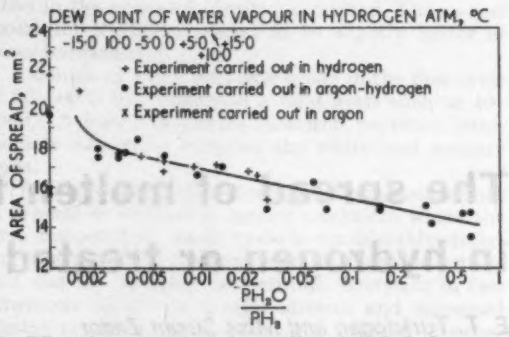
In a number of experiments the steel strips were treated with fused chloride fluxes before to the tinning operation. To assist the explanation of the observed results, a few electropotential measurements were made using iron and tin electrodes and fused chloride electrolytes.

RESULTS

Effects of reducing atmosphere

In a series of experiments, the steel strips were reduced at 750°C in pure hydrogen for times up to 100 min and then tinned at 300°C. Figure 2 shows that there is little increase in the area of spread of tin with increasing reduction time. An increase in the linear velocity of hydrogen flow through the furnace from 0·45 cm/s to 265 cm/s has little effect on the area of spread. A number of experiments were repeated five to seven times, the average values obtained being given in Fig.2; the deviations of the results were within about 2 mm².

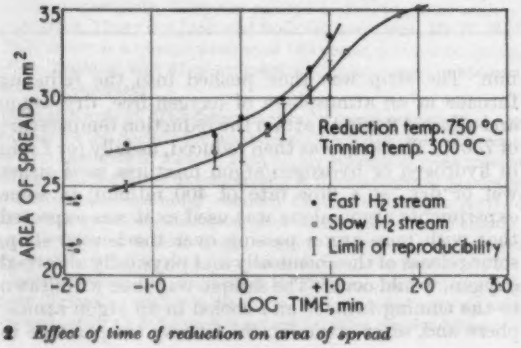
The effect of water vapour in the reducing atmosphere on the spread of tin was then investigated. The hydrogen or 1:3 argon–hydrogen mixture was humidified to a known extent by passing the gas through a mixture of solid anhydrous and dihydrate oxalic acid at a given temperature; the humidity of the reducing gas mixture was adjusted to the required value by controlling the temperature of the oxalic acid in a thermostat. In Fig.3 the area of spread of tin is plotted against the gas ratio P_{H_2O}/P_{H_2} and as would be expected, increasing P_{H_2O}/P_{H_2} ratio decreases the spreading of tin. Also given in this plot are the mean values of the areas obtained from several experiments when the steel strips were heated at 750°C in dry hydrogen, hydrogen–argon, and argon. Using hydrogen atmosphere, there is a sharp drop in the spreading of tin when a small quantity of water vapour is present in the reducing gas.



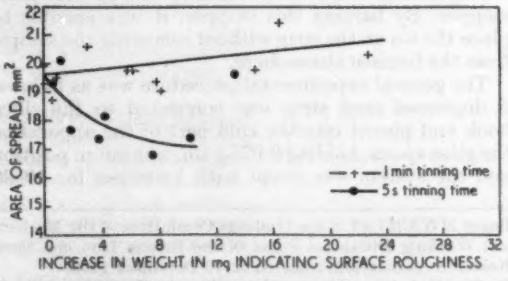
3 *Effect of water vapour on spreading of tin in hydrogen and argon–hydrogen atmosphere. Tinning temp., 350°C. Reduction temp., 750°C*

It is sometimes thought that increasing the microscopic surface roughness of the metal may increase the area of spread of molten tin or similar low M.P. metal by the capillary effect. To test this possibility the steel strips were initially oxidized to varying degrees and then the reduction–tinning operation was carried out as before. The microscopic examination indicated that the surface roughness increased when the extent of oxidation was increased so that the degree of roughness is roughly indicated by the increase in weight of the specimen during the oxidation treatment. Figure 4 shows that an increase in roughness has little or no effect on the spreading tin.

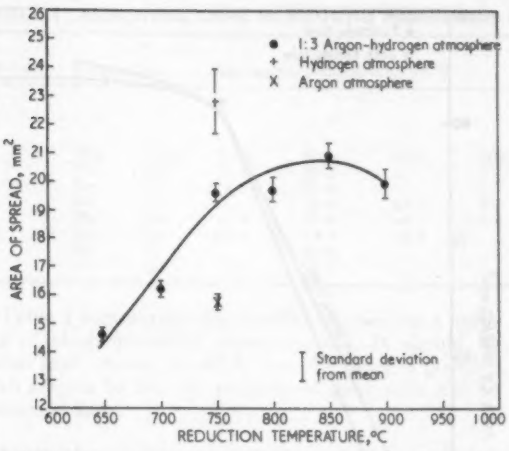
The effects of reduction and tinning temperatures are shown in Figs.5 and 6; the results indicate that the best spreading was obtained when the strips were reduced within the temperature range 750–900°C and tinned within the range 350–500°C. It should also be noted from Fig.5 that, for a given reduction and tinning temperature, replacement of hydrogen with argon reduces the area of spread of tin, as was expected.



2 *Effect of time of reduction on area of spread*



4 *Effect of surface roughness on spreading of tin in argon–hydrogen atmosphere. Tinning temp., 350°C. Reduction temp., 750°C*



5 *The influence of reduction temperature on spreading of tin. Tinning temp., 350°C*

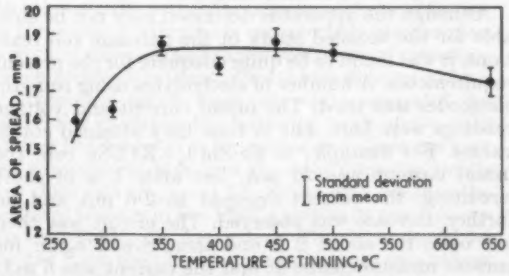
The effect of hydrogen chloride in the reducing atmosphere on the spread of tin was also investigated. The hydrogen chloride was introduced into the apparatus by bubbling pure argon–hydrogen (1:3) mixture through an aqueous solution of hydrochloric acid and drying by passage through concentrated sulphuric acid. The required partial pressure of hydrogen chloride was obtained by suitably controlling the temperature and the composition of hydrochloric acid solution. As seen from Fig.7, hydrogen chloride in the reducing atmosphere has little or no effect on the area of spread of tin.

Effect of fused fluxes

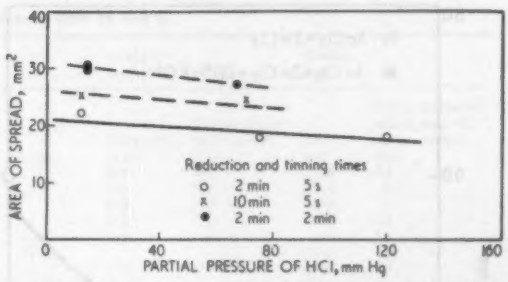
Tinning experiments were carried out using several molten chlorides or their mixture and the experimental technique was the same as that already described. The tin and flux, contained in the furnace in a glass spoon, were poured together on the steel strip. In a few experiments this procedure was modified, as will be mentioned later. In all these tinning experiments an atmosphere of dry hydrogen of 1:3 argon–hydrogen was maintained in the furnace.

In one series of experiments, increasing quantities of pure stannous chloride were used, and Fig.8 indicates that the area of spread of tin increases linearly with the amount of stannous chloride used.

In another series of experiments, 0·06 g of flux,



6 *Effect of tinning temp. on spreading of tin in 1:3 argon–hydrogen atmosphere. Reduction temp., 750°C*

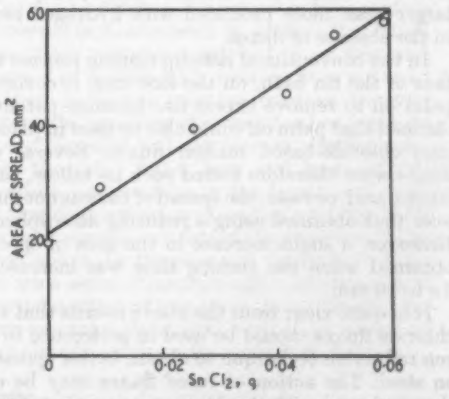


7 *Variation of area of spread with HCl content of reducing atmosphere. Atmosphere: 1:3 argon–hydrogen+hydrogen chloride. Reduction temp., 750°C. Tinning temp., 350°C*

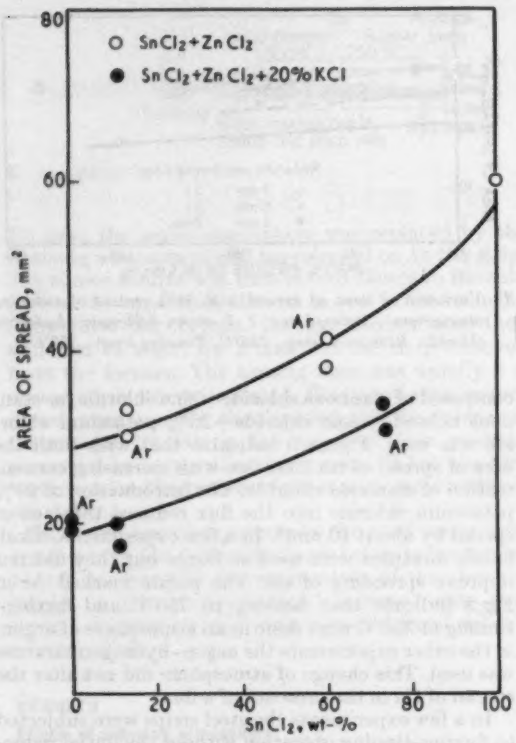
composed of stannous chloride+zinc chloride, or stannous chloride+zinc chloride+20% potassium chloride was used. Figure 9 indicates that with both the area of spread of tin increases with increasing concentration of stannous chloride. The introduction of 20% potassium chloride into the flux reduced the area of spread by about 10 mm². In a few experiments, alkali halide mixtures were used as fluxes but they did not improve spreading of tin. The points marked Ar in Fig.9 indicate that heating to 750°C and fluxing–tinning at 350°C were done in an atmosphere of argon; in the other experiments the argon–hydrogen mixture was used. This change of atmosphere did not alter the spread of tin in the presence of a flux.

In a few experiments the steel strips were subjected to fluxing–tinning operation without the initial reduction treatment at 750°C. Thus, a weighed quantity of flux was placed on the strip, pushed into the tinning zone of the furnace, allowed to attain 350°C, and tinned in the usual way. The initial tests indicated that 1 min was sufficient for the strip and its contents to attain 350°C. In these experiments the reducing atmosphere was retained in the furnace to prevent the oxidation of stannous chloride and its volatilization as stannic chloride. The results obtained for two tinning times are given in Fig.10.

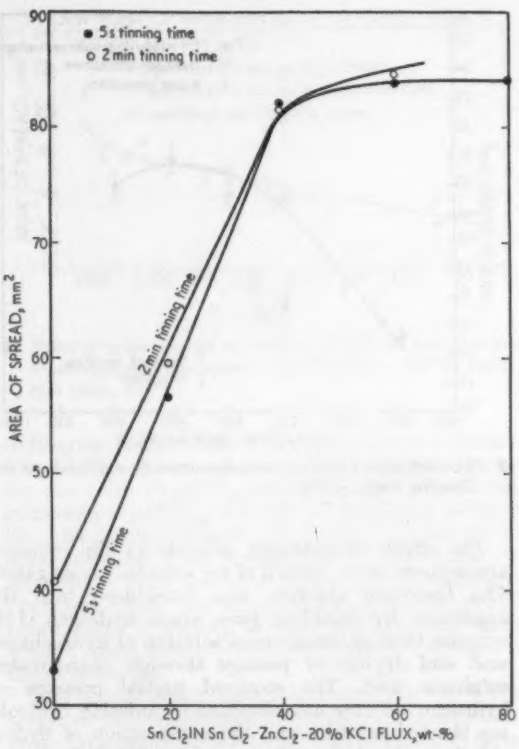
A few experiments were also conducted using aqueous flux solutions. However, only very concentrated solutions (more than 50%) gave good results,



8 *Variation of area of spread with the amount of $SnCl_2$ used as flux. Atmosphere 1:3 argon–hydrogen. Reduction at 750°C for 2 min. Fluxing and tinning at 350°C for 5 s*



9 *Variation of area of spread with* $SnCl_2$ *content of flux.* Ar *pure argon atmosphere, other points 1:3 argon–hydrogen atmosphere reduction at 750°C for 2 min. Fluxing and tinning at 350°C for 5 s. The average weight of flux used: 0·6 g*


● 5s tinning time
o 2 min tinning time
2min tinning time
5s tinning time
AREA OF SPREAD, mm^2
$SnCl_2$IN $SnCl_2-ZnCl_2$-20% KCl FLUX, wt-%

10 *Variation of area of spread with* $SnCl_2$ *content of flux. Fluxing and tinning at 350°C; flux quantity = 0·12 g*

and fluxing time had to be increased to expel the moisture contained by the flux. Therefore, the results obtained could not be compared with those given above for molten fluxes.

Attempts were also made to tin heavily scaled steel strips without reducing them in hydrogen, by placing dry flux on them and heating to the tinning temperature. Although the areas of spread were less than those obtained using fluxes on clean strips, they were still larger than those produced with hydrogen reduction in the absence of fluxes.

In the conventional hot-dip tinning process the surface of the tin bath, on the exit side, is covered with palm oil to remove excess tin. In some patents[2] it is claimed that palm oil could also be used in place of the zinc chloride-based molten fluxes. Several organic fluxes were therefore tested such as tallow, palm oil, stearic acid, or resin; the spread of tin was not increased over that obtained using a reducing atmosphere only. However, a slight increase in the area of spread was obtained when the tinning time was increased from 5 s to 10 min.

It is quite clear from the above results that suitable chloride fluxes should be used in preference to hydrogen reduction technique to obtain better spread of tin on steel. The action of fused fluxes may be electrochemical, and with this in view, some electropotential measurements were carried out on a few metal–flux–metal cells.

Electropotential measurements

The simple galvanic cell consisted of a 'test tube', $1\frac{1}{4}$ in dia. and 3 in long placed in a vertical furnace. One of the electrodes was molten tin contained at the bottom of the cell and the electrical connexion was made by a platinum wire fused in the glass. The cell was filled with a molten chloride electrode of known composition and the other electrode (iron or copper) was then inserted in the electrolyte. This electrolyte was a disc, 1 in dia., with an extension arm for electrical connexion and it was placed in the cell so that the surface of the electrode was $\frac{3}{8}$ in away from the tin electrode. To ensure that this distance was the same in all cases, a glass ring spacer of this height resting on the tube bottom was placed in the molten tin. The electrical leads from the electrodes were connected to a potentiometer and a 1·2 Ω milliammeter.

Although the apparatus described may not be suitable for the detailed study of the galvanic cell reactions, it was found to be quite adequate for the present requirements. A number of electrolytes using iron–tin electrodes was tried. The initial current and voltage readings were high, but in time they attained stable values. For example, in $Fe/ZnCl_2+KCl/Sn$ cell, the initial current was 20 mA, but after 1 h of short circuiting, the current dropped to 2·6 mA and no further decrease was observed. The circuit was then left open for about 2 h and then closed again for current measurements; at first the current was 5 mA, but after about 2 min it dropped to 2·5 mA. The stable emf obtained in this cell was 12·8 mV.

TABLE I Experimental results on electrolytic measurements of galvanic cells at 350°C

Cell no.	Electrodes		Electrolyte composition, wt-%					Stable current		Stable emf	
	Pos.	Neg.	$ZnCl_2$	KCl	$SnCl_2$	NH_4Cl	LiBr	Current, mA	Time taken to reach it, min	emf, mV	Time taken to reach emf in open circuit, min
1	Fe	Sn	77·8	22·2	...	...	...	2·6	60	12·8	10
2	Fe	Sn	78·2	21·8	...	...	...	3·6	75	13·4	5
3	Fe	Sn	...	12·2	83·7	4·1	...	0·6	20	1·0	5
4	Fe	Sn	33·0	18·4	46·1	2·4	...	0·5	2	0·9	10
5	Fe	Sn	69·7	19·5	10·8	...	...	0·1	6	0·1	10
6	Sn	Fe	...	42·9	...	...	57·1			21·0	3
7	Cu	Sn	77·8	22·2	...	...	...	3·8	55	59·0	9

Table I summarizes the results obtained on a number of electropotential measurements. It should be noted that, except in cell 6, iron or copper is positive with respect to tin; the polarity of these cells will be discussed later.

DISCUSSION

Surface tension and spreading of liquids on solid surfaces

When a drop of liquid (l) is placed on the surface of a solid (s) the surface of the substance (s) is replaced by an equal area of the surface of liquid (l) plus an equal area of the interface (ls). Representing the surface tensions of (s), (l), and the interface (ls) by γ_s, γl, and γl_s, respectively, the work of adhesion as defined by Dupre[3] is given by

$$W_a=\gamma_s+\gamma_l-\gamma_{ls} \quad \ldots\ldots(1)$$

and the work of cohesion of the liquid is

$$W_c=2\gamma_l \quad \ldots\ldots(2)$$

The difference W_a-W_c is known as the coefficient of spreading, S_{ls}, which in terms of surface tension becomes

$$S_{ls}=\gamma_s-(\gamma_l+\gamma_{ls}) \quad \ldots\ldots(3).$$

Since by definition the coefficient of spreading is the change of free surface energy of the system, it follows that spreading will occur when $S_{ls}>O$ and non-spreading, i.e. a lens formation when $S_{ls}<O$. It is sometimes erroneously stated that spreading will occur when $\gamma_s>\gamma_l$; however, this approximation applies only when γ_{ls} is quite small in comparison to γ_s and γ_l.

One of the important criteria for spreading to occur is the extent of interaction between the liquid and the solid. Considering a liquid metal/solid metal interface, spreading occurs where an intermetallic compound or a solid solution is formed; on the other hand, if the two metals do not react at all, the liquid phase remains as a lens with a very high contact angle.

In other words, with intermetallic compound formation the work of adhesion is considerably greater than the work of cohesion and so the coefficient of spreading is much greater than zero. This is best illustrated by a few examples taken from the data compiled by Bondi.[4] For example, the following table shows that although the values of γ_l for copper and silver are very close, copper spreads on iron ($S_{ls}=435$ dynes/cm) while silver does not ($S_{ls}<-1100$ dynes/cm), because the interfacial tension in the Fe–Cu system is much lower than that in the Fe–Ag system. This is as would be expected from the phase relations in these two binary systems; while in the Fe–Cu system solid solutions are formed, in the liquid and solid Fe–Ag systems very little or no solubility exists. This strong repulsion between iron and silver atoms is manifested by a very high interfacial free energy.

System	°C	γ_s, dynes/cm	γ_a, dynes/cm	γ_l, dynes/cm	S_{ls}, dynes/cm	Interaction
Fe–Cu	1100–1150	1990	1120	435	435	Complete miscibility in liquid and solid solution formation
Fe–Ag	1100–1150	1990	960	3400	<-1100	Immiscible in the liquid and solid state

Adsorption on metals

Depending on the nature of the forces between the surface of a metal (or any other substance) and the adsorbate, adsorption is usually classified as physical adsorption or chemisorption. The primary requirement in the coating of metals by metals is that the adhesion between the two metallic layers must be strong enough for practical purposes. Basically, there are two ways of achieving this: (a) the formation of an intermetallic compound or a solid solution between the coating and the base metal, or (b) the physical adsorption or chemisorption of the coating metal on the base metal. Examples were given above for the former, and now a few examples will be given for adsorption.

If the two surfaces are completely free of adsorbed gas layers, contact between them will result in immediate seizure. For example, Bowden and Young[5] cleaned iron, nickel, and platinum by heating them *in vacuo* and noted that, after cooling, a mere contact of these metals *in vacuo* caused immediate seizure. Although molten lead does not wet iron in hydrogen or in the presence of fluxes, present authors observed that lead coating can be obtained by scratching the surface or iron immersed in molten lead. If, on the other hand, the surface of the metal is scratched in air first and then immersed in molten lead, wetting does not take place. If there is any interaction between the two unlike metals, the presence of some adsorbed layer on the surface of the solid will not prevent wetting completely. On the other hand, iron and lead are immiscible and do not combine in the liquid and solid state, and therefore, adhesion of lead on iron can occur only when their surfaces are free of the adsorbed layer, as described above. In the iron and tin system, however, there are a series of intermetallic compounds and hence a partial wetting of iron by tin in an atmosphere of hydrogen can take place, that is when an adsorbed layer of gas already exists on the surface of the iron.

Effect of fluxes

In view of the difficulties involved in the removal of the adsorbed monolayer from the surface of the metal

under practical plant conditions of coating, it follows from the above considerations that the most effective method is the one which provides suitable conditions for increased rate of reaction between the coating metal and the base metal. Our experimental results indicate that this is best achieved by the use of fluxes.

Although chloride fluxes have been in use for a long time in the hot-galvanizing and tinning processes, only a limited interest has been shown in the studies of the mechanism of tinning. The early experimenters held the view that, in addition to a cleaning action, the fluxes play a more direct part in the wetting of the metal by molten solder or tin, e.g. by lowering the surface tension of the molten solder[6] or by displacing adsorbed air from the solid metal surface.[7] A valuable contribution was made by Latin[8] who demonstrated that the system solder–flux–copper behaved as a galvanic cell, and the following conclusion was reached by him: 'The superior spreading power in the chloride flux may be largely due to a tinning action which the flux exerts on the copper through the formation of stannous chloride by action on the solder. This action takes place with special rapidity near the edge of contact of the molten metal and copper, due apparently to the setting up of a local cell'. Had it not been for the formation of a local cell, a mere cleansing effect of the chloride fluxes would not have been adequate for satisfactory wetting of the metal surface. Bailey and Watkins[1] studied the flow of liquid metals on solid steel surfaces by measuring the area of spread in hydrogen and they also repeated Latin's experiments with several chloride fluxes and electrodes systems and again demonstrated the formation of a local cell.

The results from the present work given in Table I also indicate that the formation of a local cell may play an important role in the spread of molten tin on steel and the following explanation may be given to account for the observed polarity in the cells investigated.

Using the thermodynamic data compiled by Kubaschewski and Evans[9] it is found that copper could not react with chlorides of tin, iron, or zinc, unless there is an intermetallic compound formed between copper and tin, iron, or zinc. The difference in the chlorine potential between the chlorides of copper and zinc is 30 ± 5 kcal/mole at 500°C and the heat of formation of 0·4 Cu:0·6 Zn is about $-3{\cdot}0$ kcal/mole. For copper and tin, the difference in the free energies of formation of Cu_3Sn is $-7{\cdot}2 \pm 1$ kcal/mole. Considering the limits of uncertainty of the data and the lack of entropy data on the intermetallic compounds, it may be predicted that no reactions can be expected between copper and zinc chloride, but that with copper and stannous chloride an intermetallic compound such as Cu_3Sn may form. In fact, when a clean copper plate was immersed in molten zinc chloride at 400–500°C no reaction was observed, while dipping copper into molten stannous chloride resulted instantaneously in the formation of a metallic coating on the copper surface; from X-ray diffraction patterns this coating was identified as a mixture of Cu_3Sn and Cu_6Sn_5 intermetallic compounds.

Similarly, iron reacts with molten stannous chloride quite readily forming some $FeSn_2$ intermetallic compound and globules of tin adhering to the surface of the iron strip; again these phases were identified by X-ray examinations. The replacement of some of the tin by iron in stannous chloride was verified by testing for the presence of iron in the flux. On the other hand, when an iron plate was immersed in molten zinc chloride the strip was coated with a mixture of Fe–Zn intermetallic compounds as identified by X-ray examination, but no free zinc was deposited and no iron could be found in the flux after the reaction. This is as it would be expected from the thermodynamic data[9] on the system under consideration.

The formation of these iron–tin or iron–zinc intermetallic compounds can explain the polarity of the Fe/flux/Sn cells given in Table I. If iron and tin electrodes were not contaminated by side reactions in the cell, the polarity of the electrodes would have been Fe (−) and Sn (+), as predicted from the standard electrode potentials of these elements, and this in fact is illustrated by cell 6, in Table I. When the flux contains zinc and stannous chlorides, the formation of the Fe–Zn or Fe–Sn intermetallic compounds immediately raises the electrode potential with respect to tin which then attains a negative polarity. If this cell is short circuited, a current will flow through the system as a result of the solution of the tin electrode in the molten electrolyte and the deposition of tin on the 'iron' electrode.

The emf characteristics of the cells given in Table I depend on the diffusion of zinc, tin, or iron atoms through the intermetallic compound on the iron electrode, and also on the composition of the intermetallic compound. For example, the appreciably lower emf of cells 3, 4, and 5 as compared with cells 1 and 2, may be attributed to a heavy deposit of tin on the iron electrode as soon as the latter is immersed in electrolyte. Because of the electropositive nature of copper, cell 7 has the highest emf value.

The deposition of tin on iron by the galvanic cell reaction does not necessitate the presence of large percentages of stannous ions in the molten electrolyte. For example, in cells 1 and 2 the original electrolyte did not contain any stannous chloride, but on short circuiting the two electrodes externally, tin was deposited on the iron electrode; after about 6 h of cell reaction, the electrolyte was sampled and found to contain 0·3% stannous chloride and 0·5% ferrous chloride.

These results prove quite conclusively that, using zinc chloride-based fluxes, the initial stage in the hot-dip tinning process is the formation of an iron–zinc intermetallic compound on the surface of the iron which then becomes cathodic to tin, and as a result of the cell reaction, i.e. the direction of the current flow, some tin is deposited on the iron and when the latter is subsequently immersed in the molten tin bath, the surface conditioned iron is then readily wetted by tin.

An indirect, but perhaps another important role of the flux may be the removal of the adsorbed or chemisorbed monolayer of gas originally present on the surface of the steel, during the process of the formation of an iron–zinc intermetallic compound and the electrolytic deposition of tin. This would then either increase the free surface energy of the steel or decrease the interfacial tension between the new surface of the steel and that of the molten tin; in either case the area of spread of tin will increase.

After this work had been completed the authors became aware of the extensive research carried out by

Vitkin[10] on the tinning of steel strips. His interpretation of the role of stannous chloride in hot-dipped tinning largely corroborates the results and conclusions derived in this present paper.

CONCLUSIONS

When a mild steel strip is reduced in dry hydrogen or in dry argon–hydrogen mixture and then tinned, the best spread is obtained if the reduction is carried out at temperatures 750–900°C and the tinning at 350–500°C. The presence of traces of water vapour in the gas reduces the spread of tin, but introduction of hydrogen chloride into the reducing atmosphere has no or little effect on it.

Although heating of steel at 750–900°C in pure hydrogen removes the surface oxide layer, the spread of tin is quite small, presumably due to the presence of the adsorbed hydrogen layer on the steel surface.

When zinc chloride-based fluxes are used, a noticeable increase in the spread of tin is observed. Before the spread of tin, the following reactions occur at the moment the steel is immersed in the molten flux: (*a*) formation of an iron–zinc and iron–tin intermetallic compound, (*b*) setting up of a galvanic potential between this strip and the molten tin via the flux, (*c*) since the system is short circuited, there will be the solution of tin in the electrolyte and the deposition of tin on the strip from the electrolyte, and (*d*) occurrence of the above reactions presumably will free the surface from the adsorbed gas layer. This method of conditioning the surface of the steel either increases its free surface energy or decreases the iron–tin interfacial tension and consequently, increases the spread of tin.

ACKNOWLEDGMENT

The authors wish to thank Mrs P. M. Bills for her assistance in the X-ray identification work.

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Large-scale industrial vacuum plant

The Institution of Mechanical Engineers is sponsoring a symposium on 'User experience of large-scale industrial vacuum plant' to be held at 1 Birdcage Walk, London SW1, on Wednesday and Thursday, 1 and 2 March 1961. The meeting has been organized on the recommendation of the Joint British Committee for Vacuum Science and Technology, of which The Iron and Steel Institute is a constituent society.

The programme of the symposium is as follows:

Wednesday, 1 March

4.30–5.15 pm	Opening and introductory address by Mr N. A. McNeil, Chairman of the Engineers Equipment Users' Association
5.15–6.00	Tea
6.00–8.00	Metallurgical papers

Thursday, 2 March

9.30–11 am	Metallurgical papers
11–11.30	Coffee
11.30–1.15 pm	Other industrial processes
1.15–2.45	Lunch
2.45–5.30	Biological processes

The following metallurgical papers have been submitted:

Vacuum equipment for consumable electrode melting of reactive metals, *by G. W. Turner and K. Deutsch*

Industrial vacuum melting plant, *by H. C. Child, H. H. Schofield, and P. M. Gray*

Vacuum annealing of copper, *by H. W. Symonds*

Experience obtained by Springfields on the application of vacuum to full element production processes, *by A. E. Williams*

Applications of electron bombardment heating in metallurgy, *by N. F. Eaton, D. B. Gasson, and F. D. Jones*

Vacuum induction melting, *by L. S. Taylor*

The fees for the meeting are as follows: students and graduates of constituent societies of the Joint British Committee, 5*s*; other members of constituent societies, 10*s*; non-members, 20*s*. Sets of papers may be obtained by those attending for 20*s*, 25*s*, and 30*s* respectively; for those not attending the symposium, the charges are 30*s*, 45*s*, and 60*s*, respectively.

International symposium on agglomeration

PHILADELPHIA, 12–14 APRIL 1961

The American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) is sponsoring an International Symposium on Agglomeration, to be held at Philadelphia, Pa., from 12 to 14 April 1961. The symposium will deal with the processes of sintering, pelletizing, nodulizing, briquetting, powder metallurgy, ceramic bonding, and related processes, and the areas of application include ferrous and non-ferrous ores as well as carbonaceous materials, ceramics, and other non-metallic materials. Emphasis will be principally on the fundamental aspects of agglomeration.

At the seven technical sessions there will be 35 papers for presentation, from experts in Australia, Brazil, Canada, Germany, Japan, Sweden, the UK, and the USA. The full programme of papers is as follows:

Session I

Pelletizing characteristics of raw mixes for cement manufacturing, *by J. R. Tonkry (USA)*

Microstructure in binderless briquetting, *by O. G. Ingles (Australia)*

Compacting and sintering of metal powder without the application of pressure, *by H. H. Hausner (USA)*

The properties of active ceramic oxide powders in relation to sintering behaviour, *by P. Murray (UK)*

An evaluation of the properties of dolomites affecting self-fluxing sinter rates, *by R. A. Limons and H. M. Kraner (USA)*

Session II

Tumbling resistance and reducibility tests for evaluating nickel silicate ore sinters, *by T. D. de Souza Santos (Brazil)*

Properties of sinter smelted in the electrothermic zinc furnace, *by D. E. Warnes (USA)*

Advances in balling and pelletizing, *by H. T. Stirling (USA)*

Preparation of the raw material charge in the sintering of lead concentrates, *by D. Ingvoldstad and K. Kirkpatrick (USA)*

Dynamics of pelletization, *by U. N. Bhrany et al. (USA)*

Session III

The sintering of mixed powder, *by J. White (UK)*

Characterization and sintering of powders, *by H. J. Oel (Germany)*

The oxidation rates of zinc sulphide spheres, *by G. S. G. Beveridge (UK)*

Rate of densification in the sintering of uncompacted metal powders, *by F. N. Rhines et al. (USA)*

The strength of granules and agglomerates, *by H. Rumpf (Germany)*

Session IV

Engineering contributions to new techniques of iron ore agglomeration, *by M. J. Greaves and A. English (USA)*

Conventional, hot air, and mixed fired sintering, *by H. Rausch and F. Cappel (Germany)*

The basis of sinter plant design, *by R. F. Jennings and A. Grieve (UK)*

The continuous sintering process—research and applications, *by T. E. Ban et al. (USA)*

Automation of the sintering machine, *by K. Wada and K. Tsujihata (Japan)*

Session V

Pressure and water gradients through a sinter bed, *by R. Wild (UK)*

The combustion zone in the iron ore sintering process, *by R. Schluter and G. Bitsianes (USA)*

Heat hardening of artificial magnetite pellets, *by W. Callender (Australia)*

The effect of grind, temperature, and pellet size upon the quality of specular-hematite pellets, *by D. M. Ulrich and T.-M. Han (USA)*

Shrinkage of iron-ore pellets during agglomeration, *by H. V. Ross and A. Ohno (Canada)*

Session VI

Hot briquetting of partially reduced iron ores, *by J. E. Moore and D. H. Marlin (USA)*

The properties of self-fluxing sinters, *by W. A. Knepper, R. B. Snow, and R. T. Johnson (USA)*

Effects of lime on the sintering of pure hematite and magnetite concentrates, *by O. Nyquist (Sweden)*

Fundamental studies of self-fluxing sinter, *by S. Watanabe (Japan)*

Structures and bonding mechanisms in sinters made from fine-grained Australian hematites, *by L. C. Bogan and H. K. Worner (Australia)*

Session VII

Pelletizing on a horizontal grate machine, *by K. M. Haley and W. E. Apuli (USA)*

The coarse specularite–fine magnetite pelletizing process, *by K. E. Merklin and F. D. DeVaney (USA)*

The cooling of sinter, *by P. A. Young and D. A. Barnard (UK)*

Factors controlling the cooling rate of sinter, *by D. D. Phelps and J. A. Anthes (USA)*

Limits of the sinter process, *by H. Wendeborn and F. Cappel (Germany)*

Application forms and further details may be obtained from W. B. Stephenson, General Chairman, International Symposium on Agglomeration, PO Box 635, Paoli, Pa., USA.

The effect of up-quenching on the kinetics of bainite formation

J. S. White and W. S. Owen

SYNOPSIS

By measuring changes in electrical resistance, the effect of holding austenite at a temperature just above the M_s on the subsequent isothermal reaction at higher temperatures in the bainite range has been studied in a eutectoid plain carbon steel. Comparison of the reaction rate at the final reaction temperature with the rate at the equivalent stage of the direct transformation of austenite has shown that when all the steps of the reaction are carried out in the lower bainite range the kinetics are additive. When the final step is in the upper bainite range a slight retardation is observed. The significance of these results is discussed in terms of the relative rates of nucleation and growth of the bainite plates, the exhaustion of nucleation sites, and the partitioning of the austenite grains. 1861

INTRODUCTION

A NUMBER of investigations of the kinetics of bainite formation, after step-quenching entirely within the bainite range, have been reported.[1-3] In general, specimens have been held at a temperature T_H, for a time less than or greater than the incubation period, and the effect of this holding treatment on the isothermal transformation rate at a second temperature T_R has been measured. Low-alloy steels have been used in all previous investigations; however, these steels exhibit morphological features which are not found in plain carbon steels[4] and so the conclusions drawn from these investigations are unlikely to be generally pertinent.

Jaffe[1] found that for both hypo- and hypereutectoid low-alloy steels, the effect of holding for a time less than the incubation period at one temperature in the bainite range was to retard transformation at a lower temperature in the range, the extent of the retardation increasing with increasing difference between T_H and T_R. In contrast, Moore[2] found that a high-temperature holding accelerated the low-temperature reaction. Up-quenching experiments with T_H and T_R both within the bainite range have also been reported.[1] For a hypoeutectoid low alloy steel there is a retardation in the reaction at 483°C after holding within the incubation period at 455°C, but for other temperature combinations with T_R above 483°C the results are additive. For a hypereutectoid steel, the incubation time for the reaction at the higher temperature in the bainite range is reduced.

Small amounts of upper bainite accelerate transformation to lower bainite[3] but larger amounts retard the subsequent transformation and stabilize some of the austenite.[3] Lower bainite has been reported to accelerate the transformation of austenite to upper bainite.[5]

Because of the lack of basic data on the bainite reaction in low-alloy steels, it is difficult to rationalize the conflicting results of the previous step-quenching investigations. More data are available for plain carbon steels, and fundamental differences between upper and lower bainite have been demonstrated by means of electron microscopy,[6] cleavage,[7] the kinetics of the austenite to bainite reaction,[8,9] and X-ray diffraction.[10] The present step-quenching experiments were undertaken with a view to obtaining additional information about the kinetic differences between upper and lower bainite.

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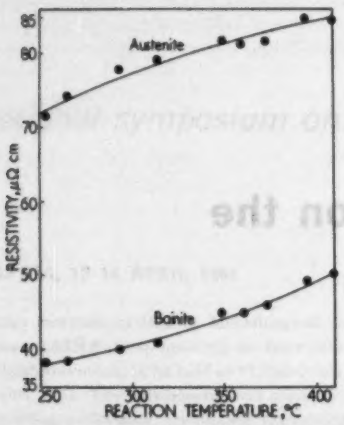
EXPERIMENTAL PROCEDURE AND RESULTS

All the specimens were made from 0·010-in dia. wire of composition, %

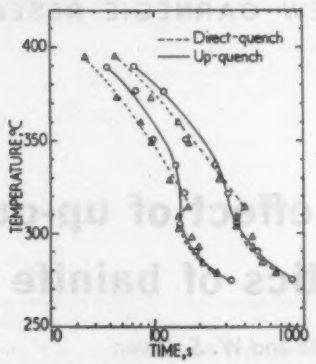
C	Si	Mn	S	P	Cr	Ni
0·80	0·25	0·52	0·009	0·022	0·02	0·04

The resistivity of the wire sample was relatively constant at points along its length and so it was concluded that the wire was homogeneous.

To carry out the up-quenching experiments, a specimen was held in an evacuated furnace maintained at 258°C (T_H). It was austenitized for 5 min at 1 100°C by independently heating it with an ac current; this was then switched off and the specimen was quenched, by an argon blast, down to the furnace temperature. After holding at T_H for the selected time it was up-quenched by reheating with an ac current. In this way it was possible to carry out a controlled up-quench from T_H within 7 s. Using the same austenitizing conditions, direct-quench experiments were performed in order to determine the TTT curve. In these experiments the specimen was held at T_H, the required isothermal reaction temperature, until the austenite transformation was complete. During the



1 *Temperature dependence of the resistivity of austenite and the variation of the resistivity of bainite with formation temperature*



2 *TTT curves obtained by direct quenching and after a prior holding at 258°C for 50% of the incubation period*

transformation a constant dc measuring current was passed continuously through the specimen. The dc potential drop between two points on the wire 5 cm apart and the emf of a chromel–alumel thermocouple also welded on to the specimen were measured and recorded throughout the experiment.

The TTT diagram for the steel was first determined and from this the appropriate holding times at 258°C were measured to enable three sets of step-quenching experiments to be performed. The holding times selected were: 50% of the incubation period τ, time to 5% transformation, and time to 10% transformation. After the treatment at T_H individual specimens were up-quenched to an isothermal reaction temperature T_R, in either the lower or the upper bainite ranges. After allowing for the austenite decomposed during the up-quench, the reaction kinetics at T_R were compared with the isothermal kinetic data obtained for the construction of the TTT diagram. From the specimens used in the initial determination of the TTT curve, the resistivity of the steel in both the completely austenitic and completely bainitic conditions was measured as a function of the transformation temperature (Fig.1).

Although the time taken for the up-quench was always less than 7 s, in most of the experiments some austenite transformed during the temperature rise, so that the bainite was formed under three different temperature conditions: during the initial holding at T_H (fraction y_H), during the up-quenching (fraction y_U), and during the final reaction (fraction y_R)

$$y_H+y_U+y_R=1 \quad \ldots\ldots(1)$$

In order to determine y_U, the resistivity change obtained by decomposition of the retained austenite at the final reaction temperature was calculated and the resistivity change which would have been obtained at that temperature for the decomposition of 100% austenite was obtained from Fig.1; thus the percentage of retained austenite was calculated by simple proportion. y_H was an experimentally controlled variable (equal to 0, 0·05, or 0·10), and so y_U was obtained from equation (1) by difference. Values of y_U are shown in Table I.

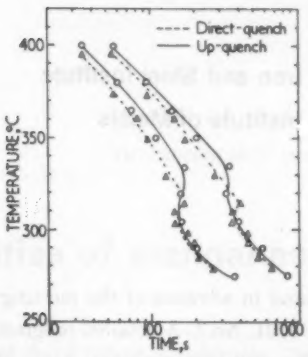
At each temperature T_R, the slope dy/dt of the reaction curves obtained by direct-quenching and by up-quenching were compared at a point on the curves corresponding to y_H+y_U reaction. In all the experiments in which T_R was between 258° and 320°C the slope was the same in the two cases, but when T_R was above 320°C the low-temperature holding was found to produce a small retardation in the rate of transformation at the high temperature. This was observed to continue throughout the reaction. To present the results systematically and to demonstrate the magnitude of the effects, the kinetic data obtained on isothermal holding after direct quenching and after up-quenching from T_H have been plotted on the same TTT diagram. To do this it was necessary to adopt a time datum at T_R, which was done by superimposing the point representing the start of the reaction at T_R in the up-quenched specimen and the point on the direct-quench reaction curve corresponding to y_H+y_U reaction. TTT curves for $y=0·50$ and 0·95 are shown in Fig.2 (for specimens held at T_H for 0·5 τ), Fig.3 (at T_H until $y_H=0·05$), and Fig.4 (at T_H until $y_H=0·10$).

DISCUSSION

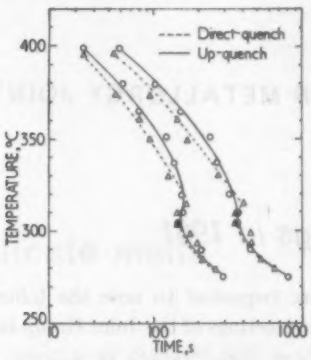
Because the intervals between reaction temperatures were small and a high-precision measuring technique was used, the lower C-curve[11] in the bainite range was clearly discernible in all the TTT curves and was unaffected by the low-temperature holding treatment. The maximum temperature of the lower C-curve range is about 320°C. In earlier work an abrupt change in the activation energy for bainite formation has been adopted as the demarcation between upper and lower bainite.[8,9] In this steel this change occurs at 350°C[11] and so the temperature range of the lower bainite reaction is somewhat greater than that of the lower

TABLE I Fraction of austenite transformed during the up-quench

	T_R in lower bainite range (258–350°C)		T_R in upper bainite range (> 350°C)	
Time of holding at 258°C	max.	min.	max.	min.
For 0·5 of the incubation period	0·0	0	0·20	0·10
To $y=0·15$	0·15	0·04	0·25	0·10
To $y=0·10$	0·20	0	0·29	0·10



3 *TTT curves obtained by direct quenching and after the prior formation of 5% of lower bainite at 258°C*



4 *TTT curves obtained by direct quenching and after the prior formation of 10% of lower bainite at 258°C*

C-curve. The most striking feature of the present results is the difference in kinetic behaviour of specimens up-quenched to above and below 320°C. This effect appears to be associated with the lower C-curve phenomena rather than with the lower bainite range as denoted by the change of activation energy.

The experimental observation that partial reaction at 258°C does not affect the reaction rate at a second temperature within the range 258–320°C demonstrates that the reaction kinetics at these temperatures are additive. That is, the transformation rate at any stage of the reaction is a function only of the volume fraction of austenite untransformed and the temperature:

$$dy/dt = f((1-y), T) \quad \ldots\ldots(2)$$

In general, reactions involving two time/temperature parameters will not be additive.[12] Thus, in the case of lower bainite there appears to be two possibilities: either the nucleation sites are exhausted early in the reaction so that the growth of the bainite plates becomes rate-controlling, or the rate of growth is rapid compared with the nucleation frequency so that the nucleation rate controls the reaction rate. From general metallographic observations the second alternative appears the more probable.

In the upper bainite range the reactions are not additive as might be expected on the ground that in this range both nucleation and growth are probably effective time-dependent parameters in the kinetics.

The retardation effect is not related specifically to the nature of lower bainite, because in all the experiments in which specimens were up-quenched into the upper bainite range at least as much reaction occurred during the up-quench as was allowed to occur at the lower holding temperature (Table I). Thus, some of the reaction product present on reaching the reaction temperature must have been upper bainite. The retardation is small at all temperatures and it appears to decrease a little with increasing reaction temperature. Two explanations of the retardation can be suggested. Microscopical examination of partially transformed specimens shows that bainite plates formed at low temperatures are long and thin whereas those formed in the upper bainite range are shorter but much thicker. Thus, a small quantity of lower bainite partitions an austenite grain effectively so that the overall reaction rate in the upper bainite range could be retarded by the restriction imposed on the growth of the upper-bainite plates. A second possibility is that the low temperature reaction destroys some of the high-temperature nucleation sites. Then, if the nucleation frequency is low (compared with lower bainite) the upper-bainite nucleation rate per unit volume of specimen could be reduced appreciably.

In the case of step-quenching carried out entirely within the lower bainite range, it is apparent that on up-quenching the plates formed at 258°C do not act as nuclei for those formed at higher temperatures, since the number of bainite plates formed must have varied depending upon the holding time at 258°C. If these could have acted as nuclei then it is reasonable to suppose that increased holding time at the lower temperature would lead to an increased rate of transformation at the higher temperature. From this it is concluded that lower bainite does not nucleate at bainite/austenite interfaces. Therefore, it must nucleate either homogeneously or at austenite grain and twin boundaries. However, the lower bainite microstructure suggest that the nucleation is probably homogeneous. Similarly the up-quenching experiments to the upper bainite range show that lower bainite plates do not nucleate upper bainite plates.

ACKNOWLEDGMENTS

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12. J. W. Cahn: *Acta Met.*, 1956, **4**, 572–575.

Meetings in 1961

Members are requested to note the following dates arranged for meetings of the Joint Group in 1961:

Monday and Tuesday, 17 and 18 April, at the Royal Commonwealth Society, Craven Street (near Northumberland Avenue), London WC2: discussion on 'The appraisal of powders for pressing and sintering'. The afternoon of 17 April will be devoted to the presentation and discussion of two review papers and two other papers under the general heading 'Techniques for the evaluation of powders'. The subject to be discussed at the morning and afternoon sessions on 18 April will be 'The relationship between powders and their pressing and sintering behaviour'. The papers will be printed in advance of the meeting in *Powder Metallurgy*, 1961, No.7. A detailed programme will be sent to all Group members.

Thursday and Friday, 7 and 8 December, at Church House, Great Smith Street, London SW1. A symposium on 'Sintered high-temperature oxidation-resistant materials'. Offers of original papers for this meeting should be sent (with synopses if possible) as early as possible to The Secretary, Powder Metallurgy Joint Group, 17 Belgrave Square, London SW1. Papers for this meeting will be printed in *Powder Metallurgy*, 1961, No.8, to be published in November.

Powder Metallurgy

Members are reminded that the fee (10*s*. or $1.85 per annum, post free) for *Powder Metallurgy* for 1961 is now due for payment. Non-members may obtain *Powder Metallurgy* for an annual subscription of 25*s*. or $3.80, post free.

Notes for Authors

A 16-page booklet entitled 'Notes for Authors' has recently been published by the Institute. It is divided into two sections, covering 'Publications' and 'Presentation at Meetings' respectively. It is designed to provide prospective authors of papers for publication in the *Journal* or for presentation at one of the Institute's Meetings with answers to all the questions they are likely to ask.

Thus the first section deals with the way in which manuscripts should be prepared, the 'house style' for abbreviations, spelling, punctuation, etc., the best way of preparing illustrations for the printer, and similar problems. The most valuable part of the second section is perhaps that giving recommendations on the preparation of slides for projection at meetings. Guidance is also given on the best way of preparing the verbal presentation of a paper for delivery at a meeting.

Copies of the booklet are available free to Members of the Institute, and may be obtained on application to the Assistant Secretary. Librarians and Information Officers of companies, research organizations, institutions, and teaching bodies, are also invited to apply for free copies.

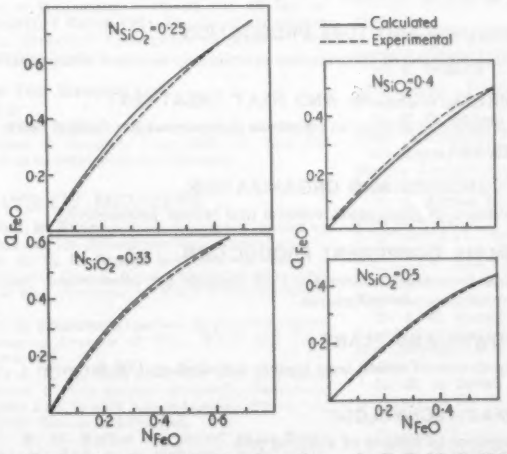
Activities of manganese oxides in silicate melts*

Dr **H. B. Bell** (Royal College of Technology, Glasgow) wrote: The paper by Abraham, Davies, and Richardson is a valuable contribution to our information on silicate melts. Reference is made in the paper to work published on the equilibrium between FeO–MnO–MgO–SiO_2 slags and liquid iron in which some preliminary results were presented, and in which for want of more data ferrous oxide was assumed to behave ideally. In the light of further results (not yet published) of a large number of melts in which the oxygen and manganese distribution was determined at 1550°C, this assumption must be revised. Using the oxygen distribution between slag and metal, iso-activity lines for ferrous oxide have been obtained for the pseudo-ternary system FeO–(MnO + MgO)–SiO_2; these show a positive deviation from ideality which is a maximum in compositions in which the ratio $\frac{N_{MnO}+N_{MgO}}{N_{SiO_2}}$ is about 2. There is a slight negative deviation in melts where N_{SiO_2} is above 0·45. It is interesting to compare these data with ferrous oxide activities in the system FeO–MnO–SiO_2, which can be calculated from the data of Abraham *et al.* for MnO–SiO_2 system and Schuhmann and Ensio[2] for FeO–SiO_2 system. The calculations are based on the assumption of ideal mixing of silicates proposed by Richardson.[3] The calculated data for the FeO–MnO–SiO_2 system are compared with the experimental data for the FeO–(MnO + MgO)–SiO_2 system in Fig.1. The agreement is close especially considering the presence of MgO in the experimental melts.

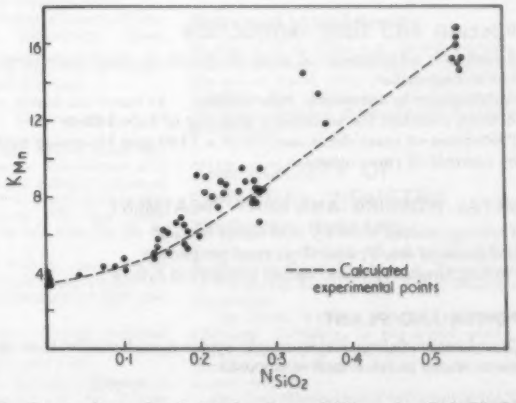
Abraham *et al.* have compared the calculated ratios of a_{MnO}/a_{FeO} with the experimental data of Bell *et al.*[1] A similar comparison can be made using the ideal mixing theory to calculate a_{MnO} in the ternary system FeO–MnO–SiO_2. Using these activities in conjunction with calculated values of a_{FeO} the effect of silica concentration on the manganese distribution between FeO–MnO–SiO_2 slags and liquid iron can be calculated. The value for the constant $K_{Mn} = a_{MnO}/a_{FeO}[\%Mn]$ in simple FeO + MnO melts is taken as 3·8 at 1550°C. This value of Gero, Chipman, and Winkler[4] has been confirmed in these experimental melts and is preferred to that of Körber and Olsen[5] used by Abraham *et al.* Calculations have been made on the effect of silica on the apparent constant $K'_{Mn} = N_{MnO}/N_{FeO}[\%Mn]$ and for any given N_{SiO_2} this was found to be independent of the ratio N_{MnO}/N_{FeO}. These calculated values have been compared in Fig.2 with those found experimentally in the study of manganese equilibrium between FeO–MgO–MnO–SiO_2 slags and liquid iron. In general the experimental quaternary data show higher values of K'_{Mn} than those calculated for the ternary slags FeO–MnO–SiO_2 but the trend is very similar. Higher values of K'_{Mn} correspond to lower values of a_{MnO} in the quaternary. The actual N_{MgO} values varied from 0·06 to 0·4 increasing with silica content as would be expected from the relevant phase diagrams. The data in Fig.2 like those in Fig.1 lend support to the theory of ideal mixing of silicates in the system FeO–MnO–MgO–SiO_2.

The data in Fig.2 for K'_{Mn} in silica saturated slags were obtained by melts made in silica crucibles and are for pure FeO–MnO–SiO_2 slags. These data agree well with the similar work of Körber and Oelsen.[5] But I would suggest the value of 3·8 for K_{Mn} in pure FeO–MnO slags should be used rather than the 2·5 of Körber and Oelsen[6] used by the authors. This would lead to $\gamma_{MnO}(t)/\gamma_{FeO}(t) = \frac{1}{3}$ in silica saturated slags rather than $\frac{1}{4}$ given by Abraham *et al.*, and would give a value of $a_{MnO(b)}$ of 0·1 (relative to liquid MnO) or 0·15 relative to solid MnO which if anything agrees better with that interpolated from Fig.1*a* of the paper.

* K. P. Abraham *et al.*: *JISI*, 1960, **196**, Sept., 82–89.



1 *Comparison of calculated values of* a_{FeO} *for* FeO–MnO–SiO_2 *system with experimental data for* FeO–(MnO + MgO)–SiO_2 *system*



2 *Comparison of calculated values of* K'_{Mn} *for* FeO–MnO–SiO_2 *system with experimental data for* FeO–MnO–MgO–SiO_2 *system*

AUTHOR'S REPLY

Professor **Richardson** (Imperial College of Science and Technology) wrote in reply: The new results submitted by Dr Bell on activities in mixtures of MnO, FeO, and SiO_2 with varying amounts of magnesia are most interesting. Those in Fig.2 provide good confirmation of the suggestions concerning ideal silicate mixing made on pages 85 and 86 of our paper. The results in Fig.1 are not such strong confirmation, because manganese dissolved in iron may have some effect on the activity coefficient of the dissolved oxygen. Thus the FeO activities derived from these oxygen concentrations could be in error. The agreement between Figs.1 and 2 should therefore perhaps be interpreted as an indication that manganese has no substantial effect on the dissolved oxygen under the conditions of Dr Bell's experiments.

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3. F. D. Richardson: Physical Chemistry of Steelmaking, 1958, M.I.T.
4. N. B. Gebo *et al.*: *Trans. AIME*, 1950, **188**, 341–345.
5. F. Körber and W. Oelsen: *Mitt. Kaiser-Wilhelm-Inst.*, 1932, **14**, 181–204.
6. F. Körber and W. Oelsen: *ibid.*, 1933, **15**, 271–309.

STAL *in English*

Number 11 (November 1960) of the cover-to-cover translation of the Russian journal *Stal'* has been published and no.12 (December 1960) will appear in March. Principal contents of these issues are given below. Full details of subscriptions to *Stal in English* are available from the Secretary of The Iron and Steel Institute.

No.11

IRONMAKING

Automation of cycle of returns at sinter plants
Pressure of burden materials in blast-furnaces

STEELMAKING

A device for adjusting thermal conditions in the OH furnace
Vacuum treatment of Bessemer steel
Roof wear with complex automatic control of OH furnaces
A radiometric investigation of burning-in and operational wear in OH furnace bottoms
Use of ground lime and iron ores in steelmaking

ELECTROMETALLURGY

Reaction between heat-resisting alloys and refractory oxides at high temperatures *in vacuo*
Intensification of steelmelting in arc furnaces

ROLLING AND TUBE PRODUCTION

Automatic adjustment of strip thickness in semi-continuous hot rolling mills
Automation in automatic tube rolling
A fixed mandrel for secondary piercing of tube billets
Protection of main-drive motors of a 1150-mm blooming mill by control of rms current

METAL WORKING AND HEAT TREATMENT

Treating molten steel by rare-earth metals
Influence of As, P, and C on steel properties
Cooling times for thick-walled cylindrical billets

POWER AND PLANT

Closed recirculating water-supply systems and purification of waste water in iron- and steelworks

GENERAL

Mechanization and automation of transport and handling operations in an iron- and steelworks

No.12

IRONMAKING

Magnetic conversion of quartzites by roasting in fluidized bed

STEELMAKING

Behaviour of sulphur when firing OH furnaces by natural gas with self-carburization

ELECTROMETALLURGY

Influence of alloying elements on behaviour of oxygen and nitrogen when melting alloys in a vacuum

FERROALLOYS

Production of manganese–silicon and ferromanganese from carbonaceous ores of Polunochnoe deposit

ROLLING AND TUBE PRODUCTION

Investigation of deformation in obliquely situated beam passes

METAL WORKING AND HEAT TREATMENT

Influence of arsenic on structure and properties of rolled heavy sections

ECONOMICS AND ORGANIZATION

Indexes of production volume and labour productivity

SMALL COMPONENT PRODUCTION

Low-temperature annealing of strands for prestressed reinforced concrete structures

POWER AND PLANT

Operation of waste heat boilers installed on OH furnaces

HEAT TECHNOLOGY

Increase of output of soaking pits

GENERAL

Working conditions in hot departments of iron- and steelworks

NEWS

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Annual General Meeting 1961

The Annual General Meeting of the Institute will be held in London on **Wednesday and Thursday, 3 and 4 May 1961.** There will be two parallel technical sessions, devoted to 'The use of computers in the iron and steel industry' and to 'Structural processes in creep' respectively. The latter will be a joint meeting with The Institute of Metals. Full details will be announced in the *Journal* shortly.

The Dinner for Members will be held at Grosvenor House, Park Lane, London W1, on the evening of **Wednesday, 3 May.**

Special meeting in USA October – November 1961

A notice is being sent to all Members giving the outline programme for the Institute's Special Meeting in the USA and Canada this year. As previously announced, the Council has accepted with pleasure an invitation from the Metallurgical Society of the American Institute of Mining, Metallurgical and Petroleum Engineers (AIME) to visit the USA in October and November.

The provisional programme provides for an official welcome in New York City on **Thursday, 19 October,** but it is anticipated that some members will arrive a day or two earlier.

Members will be able to travel to and from the USA by normal sea and air routes, but in addition aircraft will probably be chartered for Atlantic crossings at substantially reduced cost. Provisional dates for these crossings are: to New York, **Tuesday, 17 October;** from New York, **Wednesday, 8 November 1961.**

Preliminary estimates of cost are included in the programme being circulated to members.

Iron and Steel Engineers Group

As previously announced, the next meeting of the Iron and Steel Engineers Group will be held at the Offices of the Institute on the afternoon of **Wednesday, 1 March,** and all day on **Thursday, 2 March 1961.** Details of the papers to be presented were given on p.152 of the February *Journal*.

New Year Honours List

G.B.E.

Sir **Ellis Hunter,** chairman and managing director of Dorman, Long and Co. Ltd, for services to commerce and industry.

NEWS OF MEMBERS

Mr **J. H. Allan** has been appointed managing director of the Effingham Steel Works Ltd.

Mr **N. R. R. Brooke** has been appointed a director of Guest, Keen and Nettlefolds Ltd. He is also chairman of GKN Reinforcements Ltd.

Mr **A. Broomhead** has been appointed deputy managing director of Thos. Firth and John Brown Ltd.

Mr **J. R. A. Bull,** chairman and managing director of the parent company, Sanderson Kayser Ltd, is now also managing director of Kayser, Ellison and Co. Ltd.

Mr **M. W. Buttler** has joined Atlas Steels (England) Ltd as a technical sales representative.

Dr **J. M. Capus** has left The Mond Nickel Company Ltd to join the research laboratories of Gillette Industries Ltd.

Mr **B. J. Duncan** has been appointed general sales manager of W. C. Holmes and Co. Ltd.

Mr **E. T. Elwell** has been appointed a director of N. Hingley and Sons Ltd.

Dr **S. Garber** has been appointed first specialist in metallurgy to the faculty of the University of Saskatchewan, and joins the Department of Mechanical Engineering as an associate professor.

Mr **A. S. Godbehere** has left Jessop-Saville Ltd to join Foundry Services Ltd as technical representative.

Mr **S. A. R. Gray** has been appointed a director of John Summers and Sons Ltd.

Mr **E. M. Holt** has been elected to the board of Hoy Carbides Ltd as technical director.

Mr **J. H. Huntley** has retired from the chairmanship of Sir William Arrol and Co. Ltd.

Mr **J. W. Jones** has retired from his post as senior lecturer in the Department of Aircraft Materials at the College of Aeronautics.

Mr **P. Jump** has retired as a director of N. Hingley and Sons Ltd.

Professor **G. Letendre** is the elected president of the Chamber of Commerce of the Province of Quebec.

Mr **C. E. Lloyd** (*Honorary Vice-President*) has retired from the board of N. Hingley and Sons Ltd.

Mr **C. Macquarie,** general manager of Stewarts and Lloyds Ltd, Bilston, has been granted temporary leave of absence on being appointed general superintendent of the Durgapur iron and steelworks, India.

Mr **P. W. March** has been appointed deputy chairman of the Effingham Steel Works Ltd.

Mr **Q. C. McMillan** has been appointed a director of the Clyde Alloy Steel Co. Ltd.

Mr **D. Meacock** has retired as manager of the Gorseinon group of tinplate works of The Steel Company of Wales Ltd.

Dr **J. A. Naismith** has joined the board of W. T. Flather Ltd.

Mr **E. Pagett** has been appointed a director of N. Hingley and Sons Ltd.

Mr **J. F. Parker** has retired from the board of British Rolling Mills Ltd, of which he was chairman.

Mr **Andrew Pearson** has been appointed a director of the Clyde Alloy Steel Co. Ltd.

Mr **V. Pendred** is managing director of the new Head Wrightson subsidiary, Head Wrightson India Ltd.

Mr **R. D. Pollard** is now director of metallurgy with Samuel Fox and Co. Ltd.

Sir **Stanley Rawson** has joined the board of Harper Engineering and Electronics Ltd as chairman.

Mr **J. Arthur Reavell** has retired from the chairmanship of the Kestner Evaporator and Engineering Co. Ltd, and the Kestner group of companies, and has been appointed the Company's first President. He has been succeeded as chairman by his son, Mr **B. N. Reavell.**

Mr **J. H. Russell** has retired, owing to ill health, from the post of managing director of the Ecclesfield Steelworks branch of Hall and Pickles Ltd.

Mr **M. A. Scheil** has been elected national secretary of the American Society for Metals; he will hold office until October 1962.

Professor Dr-Ing. E. h. **Hermann Schenck** is now an Honorary Member of the Verein Deutscher Giessereifachleute.

Sir **Frederick Scopes** has been appointed chairman of the Oxfordshire Ironstone Co. Ltd, in succession to Mr C. R. Wheeler.

Mr **J. Ivan Spens,** O.B.E., has retired from the board of John Summers and Sons Ltd.

Mr **R. Lewis Stubbs,** O.B.E., has been appointed director-general of the Lead Development Association and the Zinc Development Association.

Mr **R. Wilcock** is now chief metallurgist of Samuel Fox and Co. Ltd.

Mr **H. Williamson** has been appointed superintendent ironmaking, Stanton Ironworks Co. Ltd.

Mr **C. E. Wrangham** has joined the board of Simon-Carves Ltd.

Mr **Peter Wrightson** is chairman of the new Head Wrightson subsidiary, Head Wrightson India Ltd.

Mr **B. P. Yates** has been appointed an additional director of Low Moor Fine Steels Ltd.

Obituary

Thorvald Andresen (*elected 1954*), in an accident near Arvida, Quebec, on 11 September 1960.

Léopold Bouvier (*Honorary Vice-President, elected 1946*), of Luxembourg, on 12 January 1961.

James Carson, O.B.E. (*elected 1951*), of Bothwell, Lanarkshire, on 9 December 1960.

Wilfred John Dawson, C.B.E. (*Honorary Vice-President, Bessemer Medallist, elected 1915*), at Bournemouth, on 22 January 1961.

Franz Leitner, DR.MONT., DR.TECHN., DIPL. ING. (*elected 1951*), of Wartberg/Muertzal, Austria, on 16 August 1960.

THE INSTITUTE OF METALS

Election of Honorary Member and Fellows

The Council of The Institute of Metals has elected Professor W. Hume-Rothery, O.B.E., F.R.S., Isaac Wolfson Professor of Metallurgy in the University of Oxford, as an Honorary Member of the Institute.

The Council has also elected Major C. J. P. Ball, D.S.O., M.C. Dr Maurice Cook, C.B.E., and Lt.-Col. S. C. Guillan, T.D., as Fellows, in recognition of the services that they have rendered to the Institute.

Retirement of the Secretary

Lt.-Col. S. C. Guillan, T.D., is retiring from the post of Secretary of The Institute of Metals at the end of April, after 50 years' service to the Institute. Col. Guillan was recently elected an Honorary Member of the Société Française de Métallurgie.

THE SOCIETY OF CHEMICAL INDUSTRY

The Society's Medal 1961

The Society's Medal has been awarded for 1961 to Sir Cyril Hinshelwood, O.M., Past President of the Royal Society and Nobel Laureate for Chemistry.

The Medal, a senior award of the Society of Chemical Industry, is presented every two years for conspicuous services for applied chemistry by research, discovery, invention, or improvements.

Sir Cyril Hinshelwood will receive his Medal from the President of the Society, Sir Alexander Fleck, K.B.E., F.R.S., at the Annual General Meeting of the Society at Oxford in July 1961.

EDUCATION

British Oxygen staff training college

The British Oxygen Co. Ltd, has opened a staff training centre at Chartridge Lodge, near Chesham, Bucks.

Priority has been given to the senior and middle levels of management, but as the college develops, a wider field will be covered: it is hoped to start courses for foremen and supervisors by the end of 1962.

All courses will be residential and will vary in length from two to four weeks; the work of the College will supplement other management development and training plans. Programmes will provide as much opportunity as possible for discussion and exchange of views.

The principal of the college is Lt-Col. T. O'G. Cochrane, and the bursar, Mr St V. E. B. Pollard.

IAESTE reports

During 1960, the thirteenth year of the activities of the International Association for the Exchange of Students for Technical Experience (IAESTE), 6430 students were exchanged among 24 member countries. In the UK 908 students were received and 883 students sent on exchange; 386 UK firms cooperated.

These figures are taken from *IAESTE Thirteenth Annual Report 1960* and *Report of IAESTE in Great Britain for year ending September 1960*. Both booklets are available from The Secretary, IAESTE(UK), 178 Queen's Gate, London SW7.

NIFES three-day courses on oil firing

Three-day courses on fuel oil firing are to be held at NIFES Office, Ailsa House, Kings Road, Reading, in March, May, June, September, November, and December 1961. The courses are designed to meet the needs of industrial plant engineers, heating engineers, and supervisory staff responsible for oil-fired boiler plant.

The fee for a course, exclusive of hotel accommodation, will be 6 *gns*. Application forms and a course syllabus may be obtained from the National Industrial Fuel Efficiency Service, 71 Grosvenor Street, London W1.

Corrosion science essay competition

The Education Panel of the Corrosion Group, with the approval of the Council of the Society of Chemical Industry, established in 1955 a competition designed to encourage those who are still in the early stages of their career to take an interest in corrosion science and to express their ideas in writing. With the support of industrialists interested in the application of corrosion science in industry, a prize of the value of 25 *gns* will again be awarded this year for an essay or paper on any aspect of corrosion of metals and its prevention.

The closing date for receipt of entries is 31 March 1961, and full details of the competition are available from the Society of Chemical Industry, 14 Belgrave Square, London SW1.

CONTRIBUTORS TO THE JOURNAL

L. G. Septier—Engineer and head of the open-hearth furnace research section, IRSID; consultant on air-pollution.

Louis G. Septier was born in Savoy in April 1927 and graduated an Ingenieur Civil des Mines, Metallurgy Section (Nancy). He joined IRSID in 1953 where he was engaged on research on air-pollution, and on pre-refining of phosphorus pig iron with pure oxygen. His later research studies have been on OH furnace problems, particularly heating, regulation, and more recently, furnace working.

B. S. Bloomfield

L. G. Septier

B. S. Bloomfield, A.I.M.—Metallurgical Branch, War Office Armament Research and Development Establishment.

B. S. Bloomfield was born in 1914. He was educated at Maidenhead County Boys School, and joined the Small Arms Section of the Metallurgical Branch ARDE in 1930. He continued his studies at Woolwich Polytechnic and The Sir John Cass Technical Institute. In 1955 he was elected an A.I.M. He is currently engaged in research on the thermal fatigue properties of metals.

Miss S. Zador

P. M. Kelly

P. M. Kelly, B.A., PH.D.—Lecturer, Department of Metallurgy, University of Leeds.

Patrick Manning Kelly was born in Panama City in 1935, and educated at the Lodge School, Barbados, West Indies. He was at Corpus Christi College, Cambridge where he gained his B.A. in Natural Science and Metallurgy (Part II) in 1957. From 1957 to 1960 he was engaged in research on the direct examination of martensite in the electron microscope at the Department of Metallurgy, University of Cambridge.

Miss S. Zador, B.SC.—Scientific Officer, BISRA, London.

Susan Zador was educated in Budapest and London. She obtained a degree in chemistry at the University of Budapest, and for a year she worked on electrical insulators in Budapest. After leaving Hungary in 1956 she worked for the Telegraph Condenser Co., Acton, as a research chemist, then in 1958 she joined the Chemistry Department of BISRA where she has worked on tinning in reducing atmospheres. At present she is engaged on atmospheric corrosion investigations.

NEWS OF SCIENCE AND INDUSTRY

Soviet technicians' visit to UK

A group of Russian technicians have offered to lecture to British industry. After a successful visit to Moscow by a 12-man delegation representing seven leading British companies, during which the British delegates visited Russian factories, and representatives of each company lectured to Russians working in the same industry, the organizer has been asked to co-ordinate arrangements for a reciprocal visit by Russian industrial representatives in April.

The party will spend two days in London and will then divide according to the industries represented. These industries will correspond with those of the British delegates who visited Moscow last December, and the seven companies are making arrangements for the Russian technicians to tour their factories. The Russians will lecture to English technicians and engineers on the latest developments in Soviet industry, in the various centres where their hosts have factories, i.e. Sheffield, Leeds, Co. Durham, Wolverhampton, Wallsend, and London.

Company news

Hilger and Watts Ltd, the largest scientific instrument maker in England, have appointed the Gelman Instrument Company as the sole American distributor of products made by Hilger's infra-red development division.

The iron- and steelmaking companies of the *GKN Group*, of which Guest Keen Iron & Steel Company Limited is one, have been amalgamated under the name of GKN Steel Company Limited. The business conducted by Guest Keen Iron & Steel Company Limited will continue under the name of Guest Keen Iron & Steel Works (Branch of GKN Steel Company Limited) under which name all transactions on behalf of this branch will be conducted and to which communications should in future be addressed.

Uranium as an alloy

In Canada a new process using uranium as a steel alloy has been patented by the Department of Mines and is now available to the steel industry. One pound of uranium is used in each ton of steel, and is said to impart strength, and resistance to corrosion, particularly at high temperatures. Patents have been applied for in the UK and a number of other European countries, as well as the USA and Japan.

New plant and equipment

The Steel Company of Wales have perfected a steelmaking process which reduces nitrogen content to negligible proportions. Known as the VLN (very low nitrogen) process, it is used in three converters installed at Margam in July 1959. An oxygen–steam blast is used, and the steel produced is consistently equal in ductility to the best which can be achieved by any other steelmaking process, the company claims. Current output of the three converters is 11 500 tons a week. A fourth converter, to be installed in 12–18 months' time, will raise this to 18–19 000 tons.

Aveley Electric Ltd have introduced into the UK the Kretz ultrasonic thickness testing instrument type series 6000, which is designed to measure dilation and contraction and ensure specified thickness levels. It is suitable for foundry and rolling mill use.

Reorganization: Reavell-Fahie Ltd

Four years ago Reavell-Fahie Ltd was formed for the main purpose of handling complete control installations incorporating Reavell-Askania regulators. Orders not involving instrumentation or installation on site have continued to be dealt with by Reavell & Co. Ltd. While there has been no difficulty in preserving this distinction internally, it has been inconvenient for those customers who sometimes require complete control equipments and on other occasions regulators only, to have to deal with both companies.

It was therefore decided that as from 2 January 1961, Reavell-Fahie Ltd, would handle all regulator sales. Future enquiries and correspondence regarding regulators should therefore be addressed to Reavell-Fahie Ltd. Invoices relating to orders placed with Reavell & Co. Ltd, before 2 January 1961, will in due course be rendered by Reavell-Fahie Ltd.

Contract news

GWB Furnaces have received an order from Steel, Peech and Tozer worth nearly £1¼ m. to provide four electric-arc melting furnaces, each of 150 tons nominal capacity.

Davy-Ashmore Ltd announce that their subsidiary, Davy and United Engineering Co. Ltd, has received an order worth approximately £300 000 from The Broken Hill Proprietary Co. Ltd for the design and supply

of two 200-ton basic oxygen converter furnaces. These furnaces will be installed in the Newcastle Works, New South Wales, of The Broken Hill Proprietary Co. Ltd.

Lodge-Cottrell Ltd announce that they have contracted to build for Dorman-Long (Steel) Ltd blast-furnace gas cleaning plant for No.1 Furnace at Dorman Long's Clay Lane Ironworks. The approximate value of the contract is £300 000. Lodge-Cottrell will also be supplying Dorman Long with precipitators for Lackenby steel plant oxygen-blown furnaces. The approximate value of this contract is £66 000.

British Industrial Gases Ltd have received an order for 87 Harris 62–2F oxy-propane blowpipes from Shipbreaking Industries Ltd.

INDUSTRIAL PUBLICATIONS RECEIVED

Built by Davy-United is a hard-covered, fully illustrated survey of the range of rolling mill engineering that the Davy-Ashmore Group is capable of executing for the metals industries. The book, while not aiming to illustrate individually every undertaking of the Group in the provision of rolling mill plant, does give a striking visual impression of the world-wide service the Group has provided. Many of the illustrations are in colour; brief text explains the essential dimensions, function, and method of operation of the equipment shown.

SKF Bearings in pinion stands is a well-printed booklet giving particulars of bearing applications for rolling mill pinion stands, details of various bearing scheme problems, and a simple method of calculating bearing loads. The illustrations are clear and well presented.

The Ball Bearing Journal No.2 1960 includes articles on suspension bearings for German tramcar motors and a heavy plate levelling machine employing SKF bearings.

The Propeller, No.7 1960 has an article on 'The coating of deep tanks', dealing with epoxide-based paint.

CORRIGENDUM

At the discussion on electrical equipment for reversing plate mills (*JISI*, 1961, Jan., **197**, 65–69) the paper 'Developments in electrical equipment for reversing plate mills', *by H. S. Brown and A. P. Baines*, was jointly presented by the authors.

In the seventh paragraph on page 68 of the same discussion the units printed as mW and mVA should read MW and MVA.

CHANGES OF ADDRESS

The new offices of *The Electrical Research Association* are at Cleeve Road, Leatherhead, Surrey (Leatherhead 4151).

The new address of the administrative and technical services of the *Groupement pour l'Avancement des Methods Spectrographiques* (GAMS) is: Laboratoire National des Essais, 1 rue Gaston Boissier, Paris XV^e: Telephone LECourbe 28–89.

The British Aluminium Company, Norfolk House, St James's Square, London SW1, has enlarged its telephone capacity to 60 lines. Its new telephone number is TRAfalgar 8888.

FORTHCOMING CONFERENCES AND EXHIBITIONS

The technical library in industry

Although the number of library and information services being set up within industrial organizations is increasing, bringing their own particular problems, there still appears to be some doubt as to what management can and should expect from such services. Aslib (The Association of Special Libraries and Information Bureaux) and the British Institute of Management are, therefore, holding a joint one-day conference on 'New technical libraries in industrial organizations' at the Connaught Rooms, London WC2, on 14 March.

Sir John Wolfenden, C.B.E., Vice-Chancellor of Reading University, will take the Chair and the speakers will include Mr R. Sewell, information officer, Research and Development Department, The United Steel Companies Ltd, who will discuss the place and scope of the library, specialist, research or management. Mr D. V. Arnold, head of the Intelligence Department, ICI (Heavy Organic Chemicals) Ltd, will consider siting, planning, and costing, and Mr W. Ashworth, librarian and information officer, British Nylon Spinners Ltd, will give a paper on the specialist staffing and general administration needed to run an international industrial library and information service.

Conference on X-ray analytical methods

A conference on X-ray analytical methods will be held by Research and Control Instruments Ltd, in conjunction with the Department of Geology at The University, Manchester, from 20 to 24 March 1961. The latest techniques and instrumentation of X-ray fluorescence analysis will be discussed and evaluated. The principles of these methods will be demonstrated with modern equipment.

Information concerning the conference, and details of registration fees may be obtained from the Conference Secretary, Research and Control Instruments Ltd, Instrument House, 207 King's Cross Road, London WC1.

Instrument conference and exhibition at Birmingham

The Society of Instrument Technology and the Birmingham Productivity Association are to hold a one-day conference at the Birmingham College of Technology, Gosta Green, Birmingham on 29 March 1961. The aim of the conference is to demonstrate how instrumentation can profitably increase productivity; an exhibition of instruments discussed during the conference will be on show, and there will be opportunities to discuss instrumentation with experts. The conference is mainly for the benefit of small-to-medium manufacturing concerns. A complete programme is available from D. Smith, Hon. Secretary, The Society of Instrument Technology, Midland Local Section, ICI Ltd, Metals Division, Kynoch Works, Witton 6.

Refrigeration and air conditioning

The 2nd International Refrigeration and Air Conditioning Exhibition will be held from 11 to 14 April at Earls Court, London. Machinery and equipment for every kind of refrigeration, air conditioning, and mechanical cooling application will be on show.

US symposium on ultrafine particles

A symposium on ultrafine particles is being planned by the Electrothermics and Metallurgy Division of the Electrochemical Society, Inc. for the Spring meeting of the Society, to be held in Indianapolis, Indiana, USA, from 30 April to 4 May 1961.

A comprehensive programme is planned with emphasis on submicron materials prepared by vaporization and condensation techniques and reactions in the vapour state.

DIARY

1–2 Mar. IRON AND STEEL ENGINEERS GROUP—Meeting—4 Grosvenor Gardens, London SW1. (*See* p.152, Feb. issue.)

1 Mar. INSTITUTION OF MECHANICAL ENGINEERS—Symposium, '*User experience of large-scale industrial vacuum plant*'—1 Birdcage Walk, SW1.

2 Mar. LEEDS METALLURGICAL SOCIETY—Lecture, '*Grain size: three-quarters of the key to strength?*', by Prof. N. J. Petch—University Staff House, University Road, Leeds, 6.30 pm.

3 Mar. SOCIETY FOR ANALYTICAL CHEMISTRY—Annual General Meeting—Meeting Room, Royal Society, Burlington House, Piccadilly, London W1, 2.15 pm.

5–16 Mar. CITY OF LIVERPOOL COLLEGE OF TECHNOLOGY—Practical course in radiochemistry—Byrom Street, Liverpool 3.

6 Mar. CLEVELAND INSTITUTION OF ENGINEERS—Lecture, '*Operational experience at Lackenby universal beam mill*', by G. W. Hendry—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 6.30 pm.

7 Mar. SOCIETY OF CHEMICAL INDUSTRY, CORROSION GROUP—Works visit—The Cleveland Bridge and Engineering Co. Ltd, Darlington, 2.30 pm. Joint Meeting with Newcastle section—Lecture, '*Metal spraying for the protection of bridge structures*', by J. D. Thompson—Technical College, Gladstone St., Darlington, 8 pm.

7 Mar. MANCHESTER METALLURGICAL SOCIETY—Lecture, '*Solidification structure of cast iron*', by I. C. H. Hughes and W. Oldfield—Manchester Literary and Philosophical Society, George Street, Manchester, 6.30 pm.

8 Mar. INSTITUTION OF MECHANICAL ENGINEERS—Symposium, '*The mechanism of combustion deposit formation and adhesion*'—1 Birdcage Walk, London W1, 4 pm.

8 Mar. NORTH WALES METALLURGICAL SOCIETY—Joint meeting with Royal Institute of Chemistry, North Wales Section, with lecture, '*The present position of physical chemistry in steelmaking*', by Sir Charles Goodeve—Flintshire Technical College, Connah's Quay, nr Chester, 7 pm.

8 Mar. SWANSEA AND DISTRICT METALLURGICAL SOCIETY—Lecture, '*Vacuum degassing*', by J. Mowat—Central Library, Swansea, 6.45 pm.

8 Mar. MANCHESTER METALLURGICAL SOCIETY—Lecture, '*Solidification and structure of cast iron*', by I. C. H. Hughes and W. Oldfield—Manchester Literary and Philosophical Society, George Street, Manchester, 6.30 pm.

8 Mar. ROYAL SOCIETY OF ARTS—Lecture, '*The steel industry today and tomorrow*', by Sir Andrew McCance—John Adam Street, London WC2, 6 pm.

9 Mar. EAST MIDLANDS METALLURGICAL SOCIETY—Lecture, '*The metallurgy of the steam turbine*', by Dr L. E. Benson—Nottingham University in the Faculty of Applied Science Building, Clifton Boulevard, Nottingham, 7.30 pm.

9 Mar. LIVERPOOL METALLURGICAL SOCIETY AND THE IRON AND STEEL INSTITUTE—Joint Meeting and lecture, '*Creep deformation*', by Dr D. M. McLean—Department of Metallurgy, Faculty of Engineering, University of Liverpool, Brownlow Hill, Liverpool 3, 7 pm.

9 Mar. EBBW VALE METALLURGICAL SOCIETY AND THE IRON AND STEEL INSTITUTE—Joint meeting and lecture, '*The effect of research and technical developments on the work of the Iron and Steel Board*', by Dr A. H. Leckie—RTB Welfare Hall, Ebbw Vale, 7.30 pm.

10 Mar. EBBW VALE METALLURGICAL SOCIETY—Annual Dinner—Lever Hall, Ebbw Vale.

13 Mar. LINCOLNSHIRE IRON AND STEEL INSTITUTE—Annual General Meeting and young members' papers—North Lindsey Technical College, Kingsway, Scunthorpe, 7.30 pm.

15 Mar. NORTH EAST METALLURGICAL SOCIETY—Lecture, '*Properties of metals at very low temperatures*', by C. J. Adkins—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 7.30 pm.

15 Mar. SOCIETY OF INSTRUMENT TECHNOLOGY—Symposium on burst slug detection in nuclear power stations—Manson House, 26 Portland Place, London W1, 7 pm.

15 Mar. INSTITUTION OF METALLURGISTS—Lecture, '*Making money as a metallurgist*', by E. G. V. Newman—Battersea College of Technology, Battersea Park Road, London SW11, 7 pm.

16 Mar. STAFFORDSHIRE IRON AND STEEL INSTITUTE—Lecture, '*The early history of iron*', by Prof. F. C. Thompson — Training Centre, Stewarts and Lloyds Ltd, Bilston, 7.30 pm.

20 Mar. SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—Joint meeting with Sheffield Metallurgical Association, with lecture, '*Technologists as successful managers*', by R. Coverdale—Engineering Lecture Theatre, St George's Square, Sheffield, 7 pm.

20–24 Mar. CONFERENCE ON X-RAY ANALYTICAL METHODS—The University, Manchester.

21 Mar. WEST OF ENGLAND METALLURGICAL SOCIETY—Lecture, '*Physical methods of analysis*', by K. M. Bills—College of Technology, Ashley Down, Bristol 7, 7.30 pm.

21–25 Mar. ELECTRICAL ENGINEERS EXHIBITION—Earls Court, London.

21–23 Mar. INSTITUTE OF METALS—Spring meeting—Church House, Westminster, London SW1. Annual dinner and dance, Thursday 23 March, Grosvenor House, London W1, 7 pm.

21 Mar. INSTITUTE OF METALS, FOR THE BRITISH NUCLEAR ENERGY CONFERENCE—Meeting, '*Compatibility problems in gas-cooled reactors*'—Church House, Westminster, London SW1, 2.30 pm.

22 Mar. INSTITUTION OF MECHANICAL ENGINEERS—James Clayton lecture, '*The application of mechanical and biological knowledge in engineering*', by Sir Frederic Bartlett—1 Birdcage Walk, London SW1, 6 pm.

22 Mar. NEWPORT AND DISTRICT METALLURGICAL SOCIETY — Lecture, '*Stainless steels*', by R. Butcher—Whitehead Institute, Cardiff Road, Newport, Mon., 7 pm.

22 Mar. ROYAL SOCIETY OF ARTS—Lecture, '*Economic and commercial aspects of the steel industry*', by Sir Robert Shone—John Adam Street, London, WC2, 6 pm.

23 Mar. SOUTHAMPTON METALLURGICAL SOCIETY—Annual General Meeting, and lecture, '*Metallurgy of ferrous welding*', by R. G. Baker—Southampton University, 7.15 pm.

24 Mar. WEST OF SCOTLAND IRON AND STEEL INSTITUTE—Symposium on heat treatment: papers by F. Darroch, D. M. Clinton, and D. M. Syme—39 Elmbank Crescent, Glasgow, 6.45 pm.

28–30 Mar. ROYAL INSTITUTION OF NAVAL ARCHITECTS—Spring meeting—10 Upper Belgrave Street, London SW1.

28 Mar. SOCIETY OF CHEMICAL INDUSTRY, CORROSION GROUP—Works visit—Northern Aluminium Co. Ltd, Banbury, 12 noon. Laboratory visit — Aluminium Laboratories Ltd, Banbury 2.30 pm. Lectures: '*The resistance of aluminium to supply waters*', by H. P. Godard; '*Behaviour of aluminium in modern power station condensate water*', by E. A. G. Croom and D. Hastings—The Crown Hotel, Banbury, 4 pm.

BRITISH IRON AND STEEL INDUSTRY TRANSLATION SERVICE

The following translations are now available, in addition to those given on page 156 of the February 1961 issue of the *Journal*:

BISITS Translation of 'Teoriya polzuchesti i dlitel'noi prochnosti petallov'. (The theory of creep and long-time strength of metals.) (From Russian.) ODING, I. A., IVANOVA, V. S., BURDUKSKII, V. V., and GEMINOV, V. N. Moscow. *Metallurgizdat*, 1959, pp.331–438. (Price: £6 10*s*. 0*d*. for each chapter, or £15 for all three.)

Part I: The ring method of testing materials in relaxation. (Chapter VII, pp.331–367.) **[1644**

Part II: Stress relaxation in metals. (Chapter VIII, pp.368–412.) **[1644**

Part III: Relaxation and creep. (Chapter IX, pp.413–438.) **[1644**

Thickness measurement of deposits, coatings, etc., using statistical techniques. (From German). GOUBEAUD, F., *Draht*, 1959, **10**, Aug., pp.370–374. (£3 10*s*. 0*d*.) **[1663**

Low-alloy ferritic steels for the manufacture of tubes, forgings, and castings for power plant. (From Czech.) ŠÍCHA, F., and FOLDYNA, V., *Hutnické Listy* (Prague), 1959, (12), pp.1097–1099. (£3 15*s*. 0*d*.) **[1669**

Directing, controlling, storing, computing: Steps in the development of drive mechanisms towards automation of rolling mills. (From German.) OPITZ, H., *Stahl u. Eisen*, 1960, April 14, pp.503–507. (£3 10*s*. 0*d*.) **[1717**

The possibilities for automation in the iron and steel industry offered by electronics. (From German.) PLETTNER, B., *Stahl u. Eisen*, 1960, April 14, pp.508–513. (£4) **[1718**

The performance of an improved 'Karol' type hammer mill. (From Polish.) SZWEDJA, F., *Koks-Smola-Gaz* (Poland), 1958, **3**, (1), pp.25–27. (£1) **[1765**

Contribution to the study of diffusion and location of hydrogen in an extra mild steel (abridged). (From French.) PLUSQUELLEC, J., *Rev. Mét. Mém. Sci.*, 1960, March, pp.215–231; April, pp.265–277. (£8 15*s*. 0*d*.) **[1786**

Cost of rolling high-quality steel bar as related to output and size of batches. (From German.) IBACH, G., *Stahl u. Eisen*, 1960, May 26, pp.744–751. (£5) **[1800**

Experimental investigation of solidification cracks in steels: the influence of impurities. (From French.) GUEUSSIER, A., and CASTRO, R., *Rev. Mét.*, 1960, Feb., pp.117. (£9 15*s*. 0*d*.) **[1824**

Research on the hot deformation of steels. II. Hot torsion tests: conclusion. (From French.) ROSSARC, C., and BLAIN, P., IRSID publication 174 bis, series A, 1958, Oct., pp.1–83. (£10) **[1835**

Moulded structural steel for pressure casting tools and moulds. (From German.) HILLER, H., *Giesserei*, 1957, March 14, pp.141–149. (£5 10*s*. 0*d*.) **[1842**

Non-destructive quality control of cast iron parts by determination of ultrasonic damping. (From German.) BIERWIRTH, G., *Giesserei*, 1960, Feb., pp.94–98. (£3 5*s*. 0*d*.) **[1853**

Active coke-breeze: its production, and suitability for the adsorption of hydrocarbons and the fine cleaning of coal gas. Laboratory tests: II. Temperature-time tests. (From German.) SPICHAL, W. H., *Brennstoff-Chemie*, 1960, (4), pp.113–119. (£5) **[1868**

An investigation of the deformation of metal in flange passes. (From Russian.) POLUKHIN, P. I., and ZHADAN, V. T., Obrabotka Stali i Splavov, Sbornik 36, (Working of steel and alloys. Collection of papers 36.) Moskovskii inst. stali im. I. V. Stalina. Moscow, *Metallurgizdat*, 1957, pp.196–227. (£7 15*s*. 0*d*.) **[1877a**

An investigation of the distribution of metal deformation throughout the cross-section of a piece rolled in a beam breakdown pass. (From Russian.) POLUKHIN, P. I., and ZHADAN, V. T., *ibid.*, pp.228–245. (£5 10*s*. 0*d*.) **[1877b**

Automatic control of production processes in iron- and steelworks. (From Swedish.) EDLING, S., *Jernkont. Ann.*, 1959, (8), pp.457–486. (£8 5*s*. 0*d*.) **[1884**

Control of cooling beds and cooling-bed shears. (From German.) VOGELSANG, H. G., *Stahl u. Eisen*, 1960, Aug. 4, pp.1067–1072. (£4) **[1885**

Preliminary observations on the detection of defects by low-temperature oxidation of fracture surfaces (0001) in zinc monocrystals. (From Italian.) SPINEDI, P., and GARBRECHT, A., *Met. Ital.*, 1960, (7), pp.411–416. (£4 10*s*.) **[1897**

Problems of welding high-tensile structural steels. (From German.) WIESTER, H.-J., *Schweissen u. Schneiden*, 1957, Oct., pp.465–468. (£3 5*s*. 0*d*.) **[1901**

Investigations on the intercrystalline corrosion of austenitic chromium–nickel steels after prolonged stressing between 450° and 800°C. (From German.) WIESTER, H.-J., and PIER, G., *Arch. Eisenhütt.*, 1959, May, pp.293–297. (£4) **[1904**

Influence of carbon and oxygen on the behaviour of some accompanying elements in iron melts under high vacuum. (From German.) FISCHER, W. A., and HOFFMANN, A., *Arch. Eisenhütt.*, 1960, July, pp.411–417. (£4 10*s*. 0*d*.) **[1906**

Steels for steam generating plants. (From German.) KREITZ, K., *Brennstoff-Wärme-Kraft*, 1960, April, pp.142–144. (£2 15*s*. 0*d*.) **[1908**

The definition and practical significance of linear thermal vectors of steels and welds. (From French.) SCHNADT, H. M., Oerlikon, Buehrle & Cie., Service des Recherches de la Fabrique d'Electrodes, Note No.601, 1960, Jan., 32p. (£5 15*s*. 0*d*.) **[1917**

Steel and steel products for nuclear power plants. (From German.) BRUHL, F., and SCHAEBEN, L., *VDIZ*, 1959, Dec. 1, pp.1645–1649. (£3 15*s*. 0*d*.) **[1923**

Development of a ribbed steel bar for concrete reinforcement. (From German.) JÄNICHE, W., *Stahl u. Eisen*, 1960, Sept. 1, pp.1185–1194. (£7 15*s*. 0*d*.) **[1926**

Hardness penetration in cold rolls during flame-hardening. (From German.) ROSE, A., and RADEMACHER, L., *Stahl u. Eisen*, 1960, Aug. 18, pp.1148–1160. (£8 5*s*. 0*d*.) **[1931**

Electron microscope study of the structure of work rolls for cold rolling. III. (From Japanese. ANDO, T. *et al.*, *Tetsu to Hagané*, 1956, March, pp.306–307. (Translated from a French version—D.C.S.: IT 3016.) (£2) **[1936**

A new mechanical strain gauge for measuring forces in the forming of metals. (From German.) FAULHABER, F., *VDIZ*, 1960, March, pp.262–264. (£3) **[1946**

Material stressing and work required in right-angled cold bending of sheet in presses, bending-off machines, and sectioning machines. (From German.) MÄKELT, H., *Industrie-Anzeiger*, 1960, March 29, pp.17–24 (383–390). (£6) **[1951**

Isothermal transformation diagrams for some standardized Swedish case-hardening steels. (From Swedish.) MOLINDER, G., *Jernkont. Tekn. Rod.*, 1960, **20**, (260), pp.711–722. (£2 10*s*. 0*d*.) **[1957**

Recrystallization of austenite in hot-worked structural steel. (From French.) GORCZYCA, S., *Rev. Mét. Mém. Sci.*, 1960, Feb., pp.153–158. (£2 15*s*. 0*d*.) **[1958**

Investigation of the behaviour of hydrogen in steel. (From Japanese.) KAWAI, M., *Tetsu to Hagané*, 1950, Dec., pp.21–25; 1951, Jan., pp.23–29. (Translated from a German version: *VDEL* B16·22. (£6) **[1966**

Economical surface treatment of sheet (grinding and polishing). (From German.) KLEINSCHMIDT, B., *Technik u. Forschung.*, 1960, Aug. 31, pp.498–500. (£2 10*s*. 0*d*.) **[1969**

The importance of through heating for the construction and operation of pusher furnaces. (From German.) I. WESEMANN, F., *Stahl u. Eisen*, 1937, March 11, pp.261–269. (£6) **[1973a**

Ways of reducing labour consumption in the foundry trade. (From Russian.) ANON, *Lit. Proizv.*, 1959, May, p.1. (£2 5*s*. 0*d*.) **[1986**

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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* Abstracts, the reference to which is marked with an asterisk, are or are to be made available as translations.

ABSTRACTS

These abstracts are also available on index cards in advance of publication in the *Journal*, each abstract being classified under the Universal Decimal system (UDC). Details and subscription notes can be obtained from the Secretary, The Iron and Steel Institute.

MINERAL RESOURCES

Chromium supplies for the French iron and steel industry (*Aciers Fins Spéc.*, 1960, July, 9–11) The application of Cr minerals is shown to fall into three categories: metallurgical, chemical, and refractory. The location of deposits is summarized and methods of production and of reducing the carbon content are indicated.—R.P.

Trace elements in manganese ores of the Visakhapatnam district J. S. R. Krishna (*J. Sci. Ind. Res.*, 1960, **19B**, July, 268–269) A letter. Spectrographic examination has shown that the Mn ores in this area of Andhra State are original sediments and that the trace elements in them are introduced by intrusive pegmatites or other paragneiss contaminations.

ORES, MINING AND TREATMENT

New facilities accelerate Chile's iron ore exports A. T. Yu (*Min. Eng.*, 1960, **12**, Aug., 922–924) An illustrated account of ship-loading facilities.

Availability of niobium (columbium) C. T. Sims (*KAPL–M–CTS–1*, 1960, March, pp.8; from *Nucl. Sci. Abs.*, 1960, **14**, July 15, 1621) A review, in which the natural occurrence, known reserves, price, and production of Nb are discussed.—S.H.-S.

Dispersion of flotation test results in the laboratory. Attempt to improve laboratory flotation apparatus P. Raffinot (*Rev. Ind. Min.*, 1960, **42**, Aug., 654–668) The technique of flotation tests is mathematically reviewed and a new laboratory apparatus is presented which is claimed to give a reduction of 50% in standard deviation for content of concentrates and in carry-over of zinc in galena concentrate.

Laboratory magnetic elutriator for purification and isolation of ferrimagnetic mineral sands W. R. B. Martin (*J. Sci. Inst.*, 1960, **37**, June, 212–215) An apparatus is described which allows almost total removal of not completely homogeneous magnetic grains from ferrimagnetic mineral sand and will further separate strongly remanent from weakly remanent grains. Magnetic field strengths and water flow velocities required for material of size 60 to 200 B.S. mesh and a scale drawing of the separation tube are given.

Flotation characteristics of goethite I. Iwasaki, S. R. B. Cooke, and A. F. Colombo (*US Bur. Mines, Rep., Invest.*, 5593, 1960, pp.25) The floatability of hematite and magnetite has been frequently investigated, whereas very little information is available for goethite or limonite, both of which are abundant in the Mesabi and Cuyuna ores. To investigate the floatability of goethite, vacuum flotation, contact angle measurement, and simplified flotation tests with a modified Hallimond tube were used. The results were correlated with the electro-kinetic properties of goethite as determined by streaming potential measurement. The results were used to interpret the batch flotation tests made on an artificial mixture of quartz and goethite.

The Ferrer Separator, a new apparatus for wet-sorting slightly paramagnetic substances J. de Robert and L. Casnabet (*Ref. Ind. Min.*, 1960, **42**, Aug., 669–676) A new apparatus for the under-water sorting of Lorraine ore concentrates is described and compared with the magnetic dry separator. Over the size distribution 200–400 μ the weight of concentrate and rate of recovery are slightly higher with the classic machine.—S.H.-S.

Beneficiation of the chromite ore of Kimpersk origin by magnetic separation V. R. Starun, I. E. Dudavskii, I. P. Davydov, M. I. Kolesnik, V. D. Ryazanteev, I. G. Samoilov, and I. N. Dokuchaeva (*Ogneupory*, 1960, (3), 108–114) The serpentines, accompanied by different chromites in the Kimpersk deposits, have a higher magnetic susceptibility than chromite ores because of the microscopic magnetite filaments which they contain. The serpentine grains themselves have no magnetite inclusions and the calcite and the quartz are also practically non-magnetic. The magnetic susceptibility for these chromium ores lies among the highest magnetic susceptibility values of the best mixtures. A scheme of enrichment is explained which decreases the SiO_2 content from 6·1 to 2·5% and that of CaO from 1·3 to 0·7%, increasing at the same time the Cr_2O_3 proportion from 51·7–53·3 to 55·6%. The yield of concentrate was found to be 82·8% giving a 89·5% extraction.

Automatic controls keep ore mill capacity at peak Trans-Weigh Co. (*Steel*, 1960, **147**, July 11, 102) An automatic grinding control system processing iron concentrates and pyrites is indicated, with diagram.—S.H.-S.

Stepwise crushing and intermediate flotation of molybdenum ores V. M. Galich and P. D. Belogai (*Tsvetye Met.*, 1960, (2), 13–17) Three methods of ore beneficiation have been tested in the laboratory; (a) two-stage crushing with intermediate flotation, (b) one crushing and one flotation (the scheme actually adopted at the plant), and (c) two-stage crushing with one flotation. The most efficient scheme is (a), giving a yield of 82·8%, and next (c) with a yield of 80·70%; and finally the simplest scheme (b) yielding 76·10%.

Investigations on iron ores by means of differential thermoanalysis H. Schenck, M. Nacken, and H. Kleeschulte (*Arch. Eisenh.*, 1960, **31**, Aug., 451–458) The equipment is described, and the curves obtained on pure materials, natural minerals, and ores are reproduced and the results discussed. (30 refs)

The transformations of Rumanian manganese and iron ores when heated O. Bolgiu and S. Ionescu (*Studii si Cercetari Met.*, 1960, **5**, (2), 281–300) The dilatometric method is quite efficient in following the behaviour of the ores during continuous heating and in controlling the roasting. The volume of all specimens increases up to 500°, thereafter the volumes of ores predominantly containing carbonates fall sharply owing to loss of CO_2 and sintering; ores predominantly MgO increase in volume up to 650° after which their volume falls. Ores predominantly iron oxides increase their volume continuously.

Transformations in oxides of aluminium and iron H. P. Rooksby (*Sil. Indust.*, 1960, **25**, July–Aug., 335–339) [In English] During the dehydration of the hydrated oxides of Al and Fe, ordered structure transitions occur. In these transitions parts of the atomic pattern of the hydrated lattice are carried over to a large extent unaltered. Some recent developments in the understanding of the nature of these transformations are discussed.—F.F.

Beneficiation of the manganese ores of Urkut, Hungary L. Visnyovszky, T. Hollo, and D. Horvath (*Koh. Lapok*, 1960, **33**, June, 245–249) By means of roasting and magnetic separation, the authors reduced the amount of manganese sand—the by-product of the washing of manganese oxide ores—to half; thus they produced a concentrate with a composition similar to that of the washed ore. Using waste nitrogen oxides, they also produced a manganese oxide with 50%Mn and practically zero iron and phosphorus from manganese carbonate ores.

The extraction of vanadium from low grade iron ores in Rumania A. Moscovici and M. Olaru (*Studii Si Cercetari Met.*, 1960, **5**, (1), 87–98) The general scheme for extracting V from these poor ores containing about 13%Fe and 0·06%V is as follows: The magnetic concentrate is pelletized with coke and fluxes. It is then smelted to iron, which is oxidized so as to obtain a slag rich in V (the initial slag contains over 90% of the total V content). The smelting is adjusted to a basicity CaO/SiO_2 = 1·2 with a 20% carbon excess. It has yielded irons with 0·6%V. These are then oxidized at

between 1250–1270° giving a slag which contains 6%V. The roasted slag is then leached in a mixture of 8% solution of H_2SO_4 when 95% of the V is extracted. This solution, with 14–16 g/l of V at pH 2, gives a precipitate of V_2O_5 which, after calcining, contains 90% V_2O_5 and traces of iron. This pentoxide is the raw material for the preparation of Fe–V.

Extraction of titanium and iron from the alluvial ilmenite concentrates A. Moscovici and G. Frumosu (*Studii si Cercetari Met.*, 1960, **5**, (2), 219–227) To obtain fluid Ti slags with a 70–72%TiO_2 and a 7–9%Fe content, carbon must be used exceeding the theoretical quantity required for the reduction of iron by a factor of 2·4–3·2. Power consumption 700–900 kW/t of ilmenite corresponding to 1600–1700 kW/t of slag. MgO in a proportion corresponding to the $MgO.2TiO_2$–TiO_2 eutectic should be introduced into the linings and the hearth and the tapping notch should be fettled with a slag rich in TiO_2 in order to protect the linings.

Combined method of complete treatment of high silicon and iron bauxites containing titanium V. D. Ponomarev, L. P. Ni, and V. S. Sazhin (*Tsvetye Met.*, 1960, (5), 44–48) An experimental verification of the main operations here proposed have proved the possibility of extracting 96–97%Al_2O_3, 98%Fe, and about 100%Ti from the ores while about 80% of the alkaline solution is regenerated from the sludge. The possibility of leaching out the alumina with alkaline solutions from the high-silicon slags, obtained in the reduction melting of the red sludge has been confirmed.

Smelting ilmenite concentrates for titanium-rich slags V. Yu. Kramnik (*Tsvetye Met.*, 1960, (5), 49–56) Experimental smelting of ilmenite concentrates with different quantities of reducing agents in the charge have shown that a first melt containing up to 20% iron oxides should be aimed at and the further reduction should be continued in the liquid phase by the addition of deoxidizers. A relation has been established between the tervalent Ti content and the proportion of iron oxides in the slag when smelting the Kusinsk or the Irshinsk ores without fluxes.

Some properties of limestone affecting its use in metallurgy O. Bolgiu and S. Fruchter (*Rev. Roumaine Met.*, 1960, **5**, (1), 187–201) [In Russian] Comparative analysis of chemical composition, microstructure, specific volume, and reactivity of Rumanian limestones of different origins have been carried out and the results tabulated. Thus marbles from Rushitsa and Alune; Karpinis and Borsek travertine; limestones from Valea Domnului Kimindia Banpotoc, Sandulest Coltsani etc. were examined.

Direct production of sponge iron in a fluidised layer of pyrites cinders G. I. Damskaya, S. S. Tikhonov, and G. Ya. Leizerovich (*Tsvetye Met.*, 1960, (4), 28–33) The method is based on the reduction roasting of pyrite cinders in a fluidized layer with natural or producer gas. The granulated cyclone dust is heated at between 850–930° so as to prevent sintering With producer gas the degree of reduction achieved is 80–82% and 55–58% of the iron consists of magnetic fractions.

A complete method for treating pyrites cinders I. I. Zaberezhnyi, I. M. Rafalovich, and E. G. Fominykh (*Tsvetye Met.*, 1960, (3), 29–37) A laboratory method is described for treating pyrites cinders by subliming the chlorides. It produces at one roasting, pellets of a chemical composition and strength suitable for smelting in the blast-furnace and eliminates in the form of chlorides the non-ferrous, rare and precious metals when 79% of the Cu, 75% of the Zn, 78% of the Au, and 68% of the Ag are recovered. The ferrous residue (the roasted pellets) forms 90% of the weight of the original charge which yields 45%Fe in addition to its other contents of 0·08%Zn and Cu, 0·15%S, and 5·5 g/t Ag and 0·35 g/t of Au. An industrial plant is now being built for this purpose.

Preparation and characteristics of magnetite and hematite pellets A. Colombo and A. Palazzi (*Met. Ital.*, 1960, **52**, July, 417–422) This article describes pelletizing tests carried out by increasing additions of very fine hematite particles and calcining at various temp. Resistance after burning is still considerable using 50% hematite. Reducibility remains unchanged after reduction, resistance falls appreciably. Mixed pellets of 50% hematite still have a resistance comparable with magnetite pellets.

Self-fluxing sinter E. H. Baldwin, I. M. Mathieson, and D. MacNeill (*W. Scotland ISI*, 1959, Dec. 18, (421), pp.26) After a theoretical discussion on the use of fluxed sinter, tests made at the Clyde Iron Works and Ravenscraig Steelworks are described in detail and it is shown that improved thermal economy can be realized in practice without detriment either to sinter plant or blast-furnace operation.—S.H.-S.

On the production of self-fluxing sinter K. Tsujihata, S. Miyakawa, S. Otsubo, S. Ono, and I. Hanaki (*Tetsu to Hagane*, 1960, **46**, April, 455–460) Using 5–10% limestone, the sinter grain size was decreased, but the amount <5 mm was also decreased. Strength was about normal. The sinter output was 4–6·5% higher, and cheaper, but in terms of iron, output and cost were hardly changed. With careful control of SiO_2 content of the ores, 100% sinter burdens could be carried on the furnace with little other material needed.

Influence of size of sinter-mix components on some sintering process factors A. G. Neyasov and A. L. Tsverling (*Stal'*, 1960, (9), 785–788) A reduction in grain size is shown to improve reducibility without impairing strength. Further reduction would only be economic if crushing, screening, and sintering capacities were available and not fully utilized.

The use of preheated and oxygen-enriched air for sintering iron ores N. E. Sidorov, V. K. Antonov, N. M. Mishchenko, and F. F. Pilipaitis (*Stal'*, 1960, (10), 878–883) Decreased fuel consumption, increased strength, and improved productivity are claimed on a basis of laboratory trials and are confirmed by industrial experiments. The application is held up by shortage of oxygen capacity.

Sinter plant is coordinated from master control room Inland Steel Co. (*Steel*, 1960, **146**, May 16, 110–112) The operation of a sinter plant with an output of 4000-t/24 h is explained. There is a central control station which is in touch with personnel throughout the plant. The strand is 8 ft wide, 168 ft long, and has 5 ignition furnaces and 21 windboxes.

The rate of oxygen removal in the reduction of iron ores with a gas mixture of carbon monoxide, hydrogen and nitrogen E. Schürmann, H. Beer, and J. Willems (*Arch. Eisenh.*, 1960, **31**, Sept., 509–519) Theoretical considerations of the influence on the rate of oxygen removal in iron ores of the temp. of reduction, rate of flow and composition of the reducing gases, and the sizing and degree of reduction of the ore are followed by a description of reduction trials on Venezuelan and Kiruna-D ores, in which the effects of these factors are investigated. (24 refs).

Electron microscopical studies on the progress of reduction of metal oxides by hydrogen. V. Electron microscopical study on the progress of reduction of fused magnetite for ammonia synthesis R. Ueda (*Nippon Kinzoku*, 1959, **23**, July, 426–429) The progress of formation of Fe particles from the magnetite granule was markedly different with and without promoter (5%Al_2O_3). The oxidation and reduction processes of reduced catalysts were examined. Spherical Fe particles were observed when the weakly magnetic part of fused magnetite (with promoters) was reduced.—K.E.J.

FUEL, PREPARATION, PROPERTIES AND USES

Mutual relations between quality indices of coking coals M. F. Kessler and V. Večeříková (*Hutn. Listy*, 1960, **15**, (7), 503–506) On the basis of detailed measurements, relations between (a) strength and cokability, (b) particle size and temp. of spontaneous ignition, (c) specific surface area and ignition point, and between (d) particle size and specific electrical resistance were established. Their physical significance and practical usefulness are discussed.—P.F.

Experiences with centrifugal dehydration of coking coal in the Ostrava coal fields J. Kmošťák and V. Klega (*Paliva*, 1960, **40**, (7), 207–212) On the basis of extensive experiments with Summy, Wedag, and Humboldt type centrifugal driers, the sieve centrifuge, last named, was found to be best.—P.F.

On the statistical assessment of homogeneity of coking coal properties J. Resler and O. Havel (*Paliva*, 1960, **40**, (8), 233–239) Theoretical and practical aspects of the assessment of moisture and ash contents, strength, etc., are discussed. The methods are considered suitable for the standardization of coke qualities, and are of increasing importance in conjunction with modern process control techniques.—P.F.

Kinetics of coal carbonization reactions in the plastic state S. Sarkar, S. C. Biswas, and A. Lahiri (*J. Sci. Ind. Res.*, 1960, **19B**, July, 246–248) A study by isolating the metaplast produced by shock-treating coal and extracting it with chloroform has determined the activation energies of a good coking coal and a semi-coking coal, and in the case of the latter some information on the possible mechanism of coke formation is presented.—S.H.-S.

The effect of alterations in bulk density of the oven charge on coking pressure characteristics and the properties of the coke produced (*BCRA, Pontypridd Test Plant Committee Report*, 1958, Dec., pp.38) Six coals were tested ranging from Coal Rank Code 204 to 602 at four levels of water addition and two of oil. The coal was crushed to the same size in each case and additional tests with finer crushing were performed on one of the coals. Within the limits tested the ultimate analysis, mean size, shatter abrasion, and micum indices of the coke produced in the test oven showed little change with alteration of the bulk density. The porosity in general decreased with increasing bulk density of the charge. No relationship was shown between the bulk densities of the charge and the coke. An attempt is made to relate the results obtained to coal rank.

Behaviour of coke at high temperatures A. S. Bruk and R. E. Leibovich (*Koks Khim.*, 1957, **27**, (3), 24–29) An investigation is described into the strength of metallurgical lump coke at temps. similar to those in the blast-furnace. Effects of secondary heating on crack development in static and dynamic testing are examined. Equipment and procedures used are described.

AIR POLLUTION AND SMOKE

Metallurgy fights air pollution L. Tarnowski (*Prz. Techn.*, 1960, **81**, (18), 31–32) It was found that Polish steelworks using ore were turning out five times as much dust as those elsewhere. It is, therefore, intended to reduce this by 50% in the next ten years. It was found that appropriate courses and intensive effort in a few works has given satisfactory results.

The measurement of airborne dust concentration in iron foundries using the Hexhlet Dust Sampler R. I. Higgins and P. Dewell (*BCIRA J. Res. Dev.*, 1960, **8**, May, 425–436) The design and principle of operation of the Hexhlet dust sampler are described. Practical instructions for its use are given and evidence is presented to show that the adverse effects of vibration can be overcome by coating the horizontal elutriator with a suitable glycerine solution.

Problem of smoke emitted by electric furnaces W. Muhlrad (*Chal. et Ind.*, 1960, **41**, Sept., 251–255) The author deals in great detail with various types of furnaces—Fe–Si, Fe–Mn, and Fe–Si–Mn, Fe–Cr and Fe–Si–Cr, Fe–W, Fe–Ni and CaC_2. Research and methods of countering smoke emission are dealt with in relation to each type of furnace.

The determination of the grain composition of powders by microscopical methods H. Gogolinski (*Rudy Met.*, 1960, **5**, (7), 281–284) The apparatus used and the sampling method employed are described. The method is suitable for testing the extent of coagulation of dust in relation to the distance from its starting-point. In addition the theoretical effects of obstacles in the dust flow are given as well as some of the practical results obtained.

TEMPERATURE MEASUREMENT AND CONTROL

Wire temperature measurement G. McH. Sturgeon (*Wire Ind.*, 1960, **27**, March, 261–263,

266) The development of contact and non-contact instruments for the measurement of wire temp. is described. The latest non-contact instruments use heat-sensitive radiation cells, with the measuring element coated with indium antimonide or similar material. A useful instrument is the Addison meter; the calibration and use of this is described. The wire completes a thermocouple circuit between pulleys of dissimilar metals. It has been found satisfactory over the following ranges: wire speed 50–3000 ft/min; temp. 50–300°C; wire sizes 9–16 swg; an accuracy of ± 5°C is obtained with a response time of 5–10 s. A similar instrument for higher-temp. application is considered possible.—D.L.C.P.

A refractory block for an immersion thermocouple for measuring the temperature of liquid steel N. I. Voronin, V. S. Gorodetskii, and V. V. Levchuk (*Ogneupory*, 1960, (3), 127–130) A design is shown of a refractory block through which a thermocouple can be inserted and immersed in the metal bath. This device is under test.

REFRACTORY MATERIALS

Refractory materials R. I. Jaffee and D. J. Maykuth (*DMIC–Memo–44*; *PB* 161194, 1960, Feb., pp.34; from *Nucl. Sci. Abs.*, 1960, **14**, June 30, 1504) Availability, extraction, consolidation, fabrication, stability, mechanical behaviour at low and high temperatures, and physical properties important in thermal stress are discussed for a number of refractory materials.—S.H.-S.

Theoretical basis of the technology of the manufacturer of corrosion-resistant refractories with regard to the modern tendencies in steel production A. S. Berezhnoi (*Ogneupory*, 1960, (3), 97–105) Because of the intensification of steelmaking processes the problem of refractories is examined from the point of view of the raw materials, of the corrosion of the linings (for which insufficient data are as yet available) of the increase in dimensions of the furnaces and especially of the temp. in the working spaces, of the interaction between lining and molten metal. Certain conclusions are drawn among which are that the principal raw material at present and in future will be periclase and other magnesia refractories, chrome-magnesite, forsterite, dolomite, with limestone additions and especially pure magnesite refractories with 20–25% chromite additions. Beneficiation and methods of equalizing the composition of the raw materials must also be applied. A number of suggestions regarding manufacture are also outlined.

Development of ultra refractory materials P. T. B. Shaffer (*AD–228359*, 1959, Nov., pp.61; from *Nucl. Sci. Abs.*, 1960, **14**, June 30, 1512) An investigation of refractory systems is reported for developing new oxidation-resistant, super-refractory materials. An oxidation furnace and a pressurizable micro-furnace are described, with measuring equipment, and a dilatometer for use to approximately 5430°F is being designed. Results of tests are indicated.

Manufacture of chrome magnesite bricks from the chromite of Shorzhinsk origin B. A. Fainerman and N. S. Mitrokhina (*Ogneupory*, 1960, (3), 105–107) This raw material has a more compact structure, can be crushed without the formation of excessive quantities of fines below 0·5 mm, and therefore produces a raw material of high bulk density without compression. The small amount of fines renders unnecessary the addition of magnesite fractions which have a deteriorating effect. The quality of the bricks from this raw material is slightly better than that made from a mixture of the Saransk and Kimpersk chromites.

Steam treatment of high Ca–Mg ores as a preliminary measure in utilizing these for making bricks Tseng Ming-hua (*Iron & Steel* (*China*), 1958, (9), 25–26; from *Sci. Abs. China, Techn. Sci.*, 1959, (1), 46) Steam is passed at rate of 52 m³/h into a 12-t cylindrical tank at a pressure of 95–100 lb/in² with temp. 480–520°C for 4 h. The product is of good quality with 4–7% (even >13%) of CaO. Yield/h is 2·8 t.

Testing periclase–forsterite bricks in OH furnace checkers A. P. Klyucherov and Kh. A. Vydrina (*Ogneupory*, 1960, (2), 85–87) Tests are reported at the Nizhne Tagil' Metallurgical works during 1958, of periclase–forsterite bricks in the checkers of the air and gas regenerators of two large OH furnaces fuelled with coke oven and blast-furnace gas, oxygen-enriched. These bricks differ from the forsterite bricks in their higher MgO and lower SiO_2 contents. The first result has shown smaller erosion but further trials are being arranged.

Silicon refractory in furnaces reduces production costs Pacific Scientific Co. (*Iron Steel Eng.*, 1960, **37**, June, 151) By using a cellular silica material to insulate their brazing furnace, Pacific Scientific Co. of Los Angeles have saved 80% of the estimated heating costs. The properties of the refractory, Foamsil, are described, and details of the furnace are given.

Production of a high-alumina cast refractory K. H. Sandmeyer and W. A. Miller (*Ind. Heat*, 1960, **27**, April, 819–824) Full details are given for the manufacture of Monofrax 'M', which is cast at 3630°F.—K.E.J.

Special refractories for ladles and other applications. I (*Ind. Heat.*, 1960, **27**, April, 834–836) Details are given of various refractories consisting of alumina or zircon sand bonded with H_3PO_4, developed for ladle lips. 'Streamers' of oxide and metal left after pouring can be detached with little or no damage to the refractory.—K.E.J.

Special refractories for ladles and other applications. II S. O. Smith (*Ind. Heat.*, 1960, **27**, June, 1270–1274) Full manufacturing and operating data are given for a high-alumina cast refractory for ladles, containing 96·5% Al_2O_3, 2·7%CaO, 0·25%SiO_2, and 0·12% alkalies (loss on ignition 0·15). Steel quality is improved through reduction of inclusions, slag defects, and misruns. Refractory and maintenance costs for the ladle are reduced. Melting capacity is increased because of the absence of slag make-up in ladles.—K.E.J.

Magnesite bricks with spinel binder possessing increased deformation temperature under load E. V. Ivanov, Ya. M. Minskii, and Z. M. Belyaeva (*Ogneupory*, 1960, (6), 281–285) The technology for the manufacture of a rectangular magnesite brick, $380 \times 150 \times 75$ mm and a wedge-like $380 \times 150 \times 125 \times 75$ brick compacted under a pressure of 1400–1500 kg/cm² in a hydraulic press is explained. The brick has increased indices for compactness, initial deformation temp. under load, and resistance to heat. It is now necessary to test this brick in the upper rows of the all-basic OH furnace.

Magnesite bricks for checkerwork of OH furnace regenerators A. N. Miroshnichenko, S. B. Vinokur, G. I. Antonov, B. P. Minkovich, M. M. Molchanova, B. A. Fainerman, and M. M. Khil'ko (*Ogneupory*, 1960, (5), 197–207) Investigations and tests during operations have established the fact that in the gas regenerators of OH furnaces, magnesite bricks made from metallurgical magnesite powder with small iron oxide contents do not spall and show a satisfactory resistance. The technology of the manufacture of a compact calcined or raw magnesite brick of small dimensions for checker work has been adjusted at the Panteleimon works. Tests in the 350 t furnaces using O_2 have demonstrated a good resistance to wear beginning from the 2nd or 3rd row from the top of the checkers, and the possibility of using these bricks for repeated campaigns with basic roofs.

Mechanism of secondary expansion of high-alumina refractories containing calcined bauxite T. D. McGee and C. M. Dodd (*Ind. Heat.*, 1960, **27**, June, 1265–1268) Excessive expansion of high-Al_2O_3 refractories containing bauxite is caused by mullite which forms between the grains or around the edges of grains. NaF prevents the effect by increasing the solubility of mullite in the liquid phase.

Thermal equilibria of the MgO–$3CaO.SiO_2$–$2CaO.SiO_2$–$3CaO.Al_2O_3$–$4CaO.Al_2O_3.Fe_2O_3$ with regard to the reaction mechanism of stabilized dolomite refractories S. Solacolu (*Studii se Cercetari Met.*, 1960, **5**, (2), 165–185) Thermal phase equilibria of the five components have been determined and the eutectic surface of the five components in which the thermal equilibrium maintains itself have been investigated. This has resulted in establishing equations which give the quantities of the liquid and solid phases in equilibrium at high temp. A conical projection diagram has been constructed of the eutectic surfaces of the five components, from which the quantities of liquid and solid phases in equilibrium can be read. The stabilized dolomite refractories have been brought into this system and a model system has been devised applicable to dolomite refractories which permits the calculation of the phase equilibrium in a ternary phase diagram.

Invariants and eutectics of the system CaO–C_2S–C_2A_2 G. Goggi (*Silicates Ind.*, 1960, **25**, July–Aug., 347–351) The above phase diagram is discussed. In this ternary system the phase denoted by C_2S contains 65% of CaO and 35% of SiO_2, while C_2A_2 consists of 47·78%CaO and 52·22%Al_2O_3.—F.F.

The physico-chemical analysis of silicate systems. (Kurnakov lecture delivered 9/12/59) N. A. Toropov (*Zhurn. Neorg. Khim.*, 1960, **5**, (4), 763–771) An historical review beginning with the theoretical work by J. Vogt in Christiania 1899 to the latest publication of the *Am. Ceram.* Soc., 1958 (44 refs).

Tests on rapid firing of runner brick (*Iron & Steel* (*China*), 1958, (9), 4–8; from *Sci. Abs. China, Techn. Sci.*, 1959, (1), 53) A furnace giving an increased rate of heating which is taken up to 1320° for 6 h and cooled 12 h is used and the firing period is reduced to 9 h 20 min. Previously it was 81 h.

Rotating hearth tests refractories Harbison–Walker Refractories Co. (*Steel*, 1960, **147**, July 25, 121) A semi-circular furnace with a rotating circular hearth used to test refractories, by exposing material alternately to high temp. and room temp. is shown.—S.H.-S.

Experiments on rapid firing of refractory bricks (*Iron & Steel* (*China*), 1958, (9), 9–13; from *Sci. Abs. China, Techn. Sci.*, 1959, (1), 49) Tests at Chungking Iron and Steel Works with chamotte bricks in down-draught kilns reduced the firing period from 80 h to 9 h 20 min and with silica bricks from 143 h to 74 h 15 min. Theoretical invdstigations are reported.

IRON AND STEEL—GENERAL

A survey of steel: The steel industry Sir Cyril Musgrave (*Financial Times*, 1959, Aug. 10, i) An introduction to a series of short articles.

The industry's research task. II. New methods of production (*Financial Times*, 1959, Aug. 10, viii) Brief non-technical notes.

Richard Thomas and Baldwins E. B. Thomas (*Steel Rev.*, 1960, **18**, April, 49–60) This article describes the expansion of RTB from the founding of the Company up to present time.

The guiding principles of the technical development of the Hungarian Iron and Steel Industry L. Czecze (*Koh. Lapok*, 1960, **93**, April, 171–180) The author, who is the head of the department of ferrous metallurgy of the Hungarian Ministry of Metallurgy and Mechanical Engineering, discusses the main objects of the second five-year plan 1960–5. The annual production of iron should increase from the present 1130000 t to 1600000 t; the annual production of steel from 1630000 t to 2400000 t; and the production of sheets from 7% to 20% of the entire rolling stock. A rod mill of 200000 t annual production at Ozd, a bar mill of 60000 t annual production in Diosgyör for rolling special steels, and a hot strip-mill with a cold strip-mill in Sztálinvaros will be constructed. Furthermore, in Diosgyör, a vacuum steel degassing plant will be built, and new methods of forging of crankshafts and axles will be introduced. The production of stainless heat resisting, and other special steels will also be increased. The specific indices of the Hungarian iron and steel industry, which are at present well below the up-to-date foreign figures, should significantly increase.—F.K.

Some thoughts on metallurgy in South Africa—the past and the future D. G. Jones (*J. S. Afr. IMM*, 1959, **60**, Dec., 193–212) An address to the Base Metals Divn., of the Institute, reviewing developments from the early 1920's and reviewing stainless steel in S. Africa, the motor car industry, metallurgical education, and alloys of the future, followed by a discussion.—S.H.-S.

Iron and steel industry in India V. D. Talmar (*Iron Coal Trades Rev.*, 1960, **181**, Aug., 419–420) A critical reply from the chief superintendent of the Bhilai steel project to an article by G. R. Bashforth on '*The Iron and Steel Industry in India*' (*ibid.*, Oct. 23, 1959) Canadian and American developments are adduced to justify the present Indian adoption of Russian practice.—S.H.-S.

Developments of iron and steel industries in India N. N. Sen (*Sci. Eng.*, 1960, **13**, Jan.–Feb., 9–17) This general survey included details of the capacity and expansion programmes of the various Indian steelplants including Rourkela, Bhilai, and Durgapur. The growth of steel capacity in India is compared with that of the UK, USSR, and USA.

Steel production in the U.S.S.R. G. Grenier (*Mines Met.*, 1960, April, 199–201) The review of recent Russian advances in steel production is concluded with certain comparative references to USA, Great Britain, and Central Europe in the field of arc-furnace output.

All-Union conference of steelmakers M. A. Pertsev (*Stal'*, 1960, (10), 900–901) A report of the conference at Stalino between 23–26 Aug. General trends and conclusions are noted.

U.S. Mission to the U.S.S.R. G. Grenier (*Mines Met.*, 1960, Oct., 559–562) This final article describes the Russian combines at Magnitogorsk and Kuznetsk and concludes the series with general observations on the techniques used at the plants visited by the Mission.

1960 shall be the year of development in iron and steel technique M. Kinugawa (*Tetsu to Hagane*, 1960, **46**, April, 453–454) Editorial.

Desiderata for iron and steel industry of Japan H. Tanimura (*Tetsu to Hagane*, 1960, **46**, May, 537–538) Editorial.—K.E.J.

The technological advancement of iron and steel making in Japan M. Yukawa (*Nippon Kinzoku*, 1959, **23**, Oct., M1–M17) Details are given of post-war advances in the industry, notably large blast-furnaces, ore beneficiation, use of oxygen in steelmaking, combustion control of soaking pits, and reheating furnaces rolling of heavy plate, manufacture of strip, galvanizing, and tinning.—K.E.J.

Correlation between science and practice in the iron and steel industry H. Schenck (*Stahl Eisen*, 1960, **80**, Oct. 13, 1377–1382) The golden jubilee lecture of the foundation of the Naumann Institute für Eisenhüttenkinde sowie für Metallhüttenkunde und Elektrochemie of the Technische Hochschule, Aachen.

Absorption and activated absorption in metallurgical processes W. Kuczewski (*Katedra Met. Zel. Polit. Czest.* 1958, III, pp.15) Neither the theory of physical absorption nor that of activated (chemical) absorption can be applied successfully to the reactions in iron- and steelmaking furnaces because the potential of these reactions, being affected not only by the number of phases but also by their allotropic modifications, is not constant.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Progress in blast furnace practice K. Wada (*Tetsu to Hagane*, 1960, **46**, May, 589–597) A review (11 refs).—K.E.J.

Modern trends—sintering plants and blast furnaces D. P. Cromwell (*Iron Steel Eng.*, 1960, **37**, June, 127–132) A brief historical review of early blast-furnace and of the present-day position is followed by an estimate of likely future developments.

Heat balances and coke consumption in the blast furnace A. Poos and A. Decker (*Centre Nat. Rech. Met.*, 1960, reprint, pp.16) [In English] The conventional blast-furnace heat balances do not take into consideration the amount of indirect or direct reduction—very important factors which relate the coke rate to the top gas analysis. In addition it is not possible to establish directly in kg of coke the effect of the various factors on the coke rate. This article describes a method of calculating the balance which enables every factor to be expressed in kg of coke and can be used to estimate coke consumption. They also check the equivalence of the classical heat balance and their method of calculation. Finally, they give practical examples of the new method.

Experiences on the increase of output of a small blast furnace Wang Tsun-fong and Wang Jen-chung (*Iron & Steel (China)*, 1959, (4), 103–105; from *Sci. Abs. China, Techn. Sci.*, 1959, (3), 218) The operation of a blast-furnace of 17·5 m^3 capacity is described in detail.

Experiences in increasing output of the Whang Je-koung blast furnace Lui Chi-chao and Tang You-yu (*Iron & Steel (China)*, 1959, (6), 182–187; from *Sci. Abs. China, Techn. Sci.*, 1959, (3), 225) A brief note on a 0·5 m^3 blast-furnace and its operation.—S.H.-S.

Investigation of the raceway in front of a tuyere on a three-dimensional hydraulic model V. G. Manchinskii and A. F. Zaitsev (*Stal'*, 1960, (9), 774–779) A plastic model is described simulating a blast-furnace and used to investigate the processes and factors in the course taken by the jet injected through the model tuyere.

The effects of increased gas pressure on the chemical composition of pig iron V. N. Andronov (*Stal'*, 1960, (10), 902–904) Si and Mn contents decrease and temp. rises. The theoretical treatment of Khener, Pokryshkin, and Shchedrin is questioned as the blast-furnace is not in fact an isothermal system. The problem of the high-silicon irons is dealt with in particular.

Progress in the manufacture of heat resisting materials J. Stachurski (*Prez. Techn.*, 1960, **81**, (18), 24–26) Though blast-furnace lining products are today of good quality, work is going on to improve their heat resisting qualities and their physical properties. In addition the manufacture of products containing 55% Al_2O_3 is due to begin.

Increasing blast-furnace driving rate with simultaneous reduction in coke rate Tso Feng-i (*Stal'*, 1960, (9), 780–784) Gas flow distribution, higher blast temp., higher metal content and reduced coke ash, the use of fluxed sinter, removal of fines, and improved tuyere design, improved production and decreased coke rate, and factors controlling driving rate are discussed.

Study and measurement of blast-furnace lining wear I. G. Polovchenko, V. N. Afanas'ev V. N. Uzlyuk, A. A. Krivosheev, and N. D. Yaroshevskii (*Stal'*, 1960, (9), 769–774) A tracer method is described. Low-activity sources are recommended.

Works experience with 'hot top' blast-furnaces in the Kiement Gottwald steelworks F. Marek (*Hutník*, 1960, **10**, (8), 297–302) An account is given of the performance of blast-furnaces operating with increased top pressure, and modification of the design of blast-furnaces necessitated by this mode of operation are discussed. Experience in Czechoslovakia confirms that it is economical.—P.F.

Thermodynamical and stochiometrical analysis of blast furnace processes W. Kuczewski (*Katedra Met. Zel. Polit. Czest.*, 1957, I, pp.45) With the increase of the temp. of the blast the coke rate decreases owing to the increased deposition of carbon according to Bell's reaction. A formula is given for calculating the amount of the coke oxidized by CO_2 from carbonates and from Bell's reaction, from which it follows that the best working conditions exist when the amount of carbon deposited is greater than that which has been oxidized by CO_2.

Operation with self-fluxing sinter in the blast furnace K. Tuzihata, M. Inoue, N. Nakamura, M. Yoshinaga, and K. Yasuda (*Tetsu to Hagane*, 1960, **46**, May, 539–548) Data are given for nine months' operation of Kukioka No.2 B.F. with self-fluxing sinter. Iron production of above 1200 t/day was achieved; this corresponds with productivity of over 1·4 t/day/m^3. A coke rate of 518 kg/t was recorded.

On the mechanism of the reduction of iron oxides S. T. Rostovtsev, L. N. Rudenko, and B. K. Simonov (*Nauchn. Doklady Vyssh. Shkoly-Metallurgiya*, 1959, March–April, 5–8) The part played by the lower oxides as catalysts of the semiconductor type, the distinction between chemical and phase transformations, with the diffusion of iron constituting a close bond between them, and a two-stage scheme of reduction mechanism are discussed. In this scheme the first stage occurs with, and the second without phase transformation. The activated adsorption of the reducing gas on the oxide surface is the initiating factor in the process of reduction.

Production of low-sulphur pig iron at the Magnitogorsk Combine I. P. Bardin, I. S. Kulikov, V. M. Zudin, L. M. Tsylev, G. A. Sokolov, A. L. Galstonov, N. N. Babarykin, and I. I. Gul'tyai (*Stal'*, 1960, (10), 865–869) The process and trials leading to it are described, and iron with 0·022–0·027%S is regularly produced by using more MgO in the slag.

The equilibrium of the sulphur reaction between molten, carbon-saturated iron and lime–silica–alumina slags H. Schenck, M. G. Frohberg, and T. el Gammal (*Arch. Eisenh.*, 1960, **31**, Aug., 471–472) The influence of alumina in CaO–SiO_2 slags on the sulphur equilibria with liquid, carbon-saturated iron at 1550°C was investigated. It was established that Al_2O_3 contents up to 26% produced no change in the equilibrium conditions for CaO–SiO_2 slags.

Isotopes permit continuous blast furnace wear check Colorado Fuel and Iron Corp. (*Steel*, 1960, **147**, July 25, 126–127) The use of ^{60}Co to give continuous measurement of lining wear in the throat area of a blast-furnace is described.—S.H.-S.

Flame-cleaning a blast furnace (*Torch*, 1959, Summer, 21) A short description of flame cleaning of blast-furnace shells at Appleby-Frodingham Steelworks to remove scale. Using British Oxygen Saffire oxyacetylene equipment the job was completed in seven days.

Treatment of the sludge from the blast furnace purification plant at the Kuznetsk Metallurgical Combine F. A. Baryshnikov and M. N. Kaloshina (*Tsvetye Met.*, 1960, (1), 57–59) A rough analysis of the sludge revealed appreciable contents of Al, Na, K, Zn, and Mn, a smaller proportion of Ti, Cu, and Pb and very small amounts of V, Ni, Co, Cr, Ag, Cd, Sn, and Ga. The greater part of iron in the sludge is in the form of non-magnetic oxides which have to be transformed into magnetic oxides to be separated magnetically. This could give concentrates of 61·50% of iron with recovery of 84·95%. Laboratory tests have shown the economic possibility of extracting zinc and incidentally also, a few non-ferrous and rare metals.

Studies on the electric pig iron smelting of iron sand. I. Influence of the reducing conditions on the chemical composition of pig iron A. Murakami, K. Takai, and Y. Sato (*Tetsu to Hagane*, 1960, **46**, April, 460–466) Reducing conditions were studied for molten ore-flux mixes. With increase of temp., Si, Mn, and Ti contents of the iron were increased, and S decreased. With increase of slag basicity, Si and S contents were decreased, Mn increased, and Ti increased gradually. With increase of ΣTiO_2 in slag, Si, Mn, and S contents were decreased and Ti increased to a const. value. The lowest melting temp. (1260–1310°C) of TiO_2-containing slag is found with ΣTiO_2 in slag of 20–25% and slag basicity 0·7–0·8.

Desulphurization of pig iron by lime blowing (*Iron & Steel (China)*, 1958, (11), 17–19; from *Sci. Abs. China, Techn. Sci.*, 1959, (1), 55) Tests are reported with concentration of lime maintained at 30–40 kg/m^3 and time of desulphurization is 5–10 min. Lime particle size is $<0{\cdot}42$ mm and its ignition loss $>20\%$. Efficiency of desulphurization is $>90\%$.

The rotating ladle:—a new metallurgical device for the desulphurizing of iron F. Gauzzi (*Fond. Ital.*, 1960, **9**, July–Aug., 321–324) A plant operated by Mannesmann Meer AG is described which desulphurizes hot iron without external application of heat. A comparison is made of desulphurizing with lime powder and calcium carbide through the temp. changes they cause in the metal bath. The possibility is suggested of combining lime desulphurization (an endothermic reaction) with an exothermic reaction, such as deoxidation using ferro-silicon, aluminium, calcium silicide etc.

PROPERTIES, TREATMENT AND USE OF SLAGS

Blast furnace slags as a commercial product P. Kielski (*Hutnik*, 1951, **18**, (6), 225–227) Suggestions for the use of slag are made.

A new scale of basicity in oxide slags and the basicity of the slags containing amphoteric oxides K. Mori (*Tetsu to Hagane*, 1960, **46**, April, 466–473) $B = 10\ [(r - r_0)/C]$, where $r = Fe^{3+}/(Fe^{3+} + Fe^{2+})$, r_0 is the value for pure iron oxide, and $c = \Sigma M/(\Sigma Fe + \Sigma M)$, where $\Sigma Fe = Fe^{3+} + Fe^{2+}$ and $\Sigma M = Ca^{2+} + Si^{4+} + Ti^{4+} + Al^{3+}$. . . . Primary, binary, and tertiary slags are studied, and ways of determining B explained. Values are as predicted from metal–oxygen bond strength. An isoelectric point is found where additions of TiO_2 or Al_2O_3 do not alter the CaO/SiO_2 ratio (18 refs).—K.E.J.

Correspondence on **Activities of manganese oxides in silicate melts** K. P. Abraham, M. W. Davies, and F. D. Richardson (*JISI*, 1961, **197**, March, 245–246) [This issue].

Reduction reactions between molten slags containing titanium oxide and pig iron and the behaviour of titanium oxide K. Mori (*Tetsu to Hagane*, 1960, **46**, May, 548–555) Studies were made of the reduction of Ti and Si from slags of the system $CaO–SiO_2–TiO_2$ into C-saturated iron in a graphite crucible at 1550°C. The slag composition is related to $K_{Ti,\,Si} = \{[Ti]\ [Si]\}/\{(Ti)\ [Si]\}$, which is correlated with B_L on a new scale of basicity. Applications to electric-furnace practice are discussed (15 refs).

DIRECT PROCESSES

Direct reduction of iron ores N. N. Dobrokhotov and K. E. Makhorin (*Izvest. VUZ-Chern. Met.*, 1958, (10), 3–13) In the Russian-developed process described, rich ores or concentrates are reduced by water-gas obtained by partial combustion of natural gas with oxygen. Mechanism, economic factors, and two types of plant—a fluidized-bed reactor and a low-shaft furnace—are described.

Direct iron processes R. B. Elver (*Min. J.*, 1960, **255**, July, 29, 127) An account of a publication by the Ottawa Dept. of Mines and Technical Surveys, No.40.

Steelmaking direct from mineral ores (*Proc. Metallurgy (China)*, 1958, (45), 22–23; from *Sci. Abs. China, Techn. Sci.*, 1959, (1), 45) Steelmaking in 53 gal. gasoline tanks lined with refractory materials, using iron ore, limestone, and fluorspar, with coke or charcoal as fuel is described. The product is medium-carbon steel and the total time required is 3–3·5 h.

PRODUCTION OF STEEL

Choice of technology in steel P. H. Kutar (*Trans. Indian Inst. Met.*, 1960, **13**, June, 107–118) The technology of iron and steelmaking processes are reviewed in relation to the future expansion of the Indian industry and the advantages of modern developments are emphasized.—A.D.H.

Metallurgical theories in the service of the steel-making industry W. Kuczewski (*Katedra Met. Zel. Polit. Czest.*, 1958, II, pp.11) A review of metallurgical theories and their application in blast-furnace and pneumatic steelmaking processes precedes a list of problems still to be solved such as dephosphorization and desulphurization of iron and steel, the elimination of the OH process by cheaper and quicker methods, the part played by absorption in metallurgical processes, and reactions between oxygen, powdered lime, and the metallic bath.

Steelmaking: the impact of oxygen (*Steel Rev.*, 1960, Oct., (20), 2–4) A general account with statistics of oxygen consumption.

Joint action to streamline steel production W. Pohle (*Financial Times*, 1960, March 28, supplement, 35–36).

Extensive new facilities scheduled to produce oxygen (*Iron Steel Eng.*, 1960, **37**, June, 142) The facilities scheduled by Linde Co. Division of Union Carbide Corp. envisage an increase of 4000 t/day in O_2 producing capacity. Details of the proposed plants are given.

The effects of humidity on melted iron (*Fonderie*, 1960, **9**, Aug., 361–368) This is a summary of the results of a study undertaken in Japan. The conclusion is that humidity increases surface oxidation before it is melted and this film of oxide which is formed oxidizes the fused metal increasing the thickness of the temper zone of hardening, the inclusion of oxide and especially the SiO_2. The stream which is in direct contact with the melted metal does not appreciably increase oxidation. In the oxidizing process by humidity before melting, piping increases. The humidity of the blown air increases the oxidation of the metal in the lower melting areas and is harmful to the castings, increasing the hardening tendency and the formation of piping.

The metal-slag distribution in steel production G. Violi (*Università di Trieste Inst. Chim. Applicata*, 1959, (8), pp.15) [In Italian] The Mn distribution is calculated theoretically and then the Mn content of the steel is checked in 59 heats, in English OH furnaces and one electric crucible furnace, and the results are tabulated. These are satisfactory enough and under normal conditions the Mn reaction almost always reaches the equilibrium.

Developing an optimum melting practice for 20KhGNR steel to replace 20KhNA steel G. A. Hasin and V. N. Davidyuk (*Stal'*, 1960, (9), 808) A note from Zlatoust.

Engineering the 1955–1958 Inland Steel Co. expansion programme I. Rosenak (*Iron Steel Eng.*, 1960, **37**, June, 96–104) Details of site development, which included filling in over 500 acres of Lake Michigan, are given, and a description is given of the expansion of steel-making and rolling facilities.

Repairing the linings of metallurgical furnaces with a fettling gun B. A. Velikin (*Tsvetye Met.*, 1960, (4), 34–41) A plea is made for a wider use of the fettling gun and a new gun design is introduced for which certain advantages are claimed.

On the pneumatic processes of converting high-phosphorus iron P. Coheur (*Centre National Recherches Tech.*, 1960, reprint, pp.12) [In English] The article describes first the development of the basic Bessemer technique from 1938 to 1958, the evolution of processes using bottom-blown converters and the LD and LD, AC top-blown converter processes. The present tendency to use oxygen-enriched air or oxygen-steam mixtures results mainly from the price structure of pig iron and scrap and the need for steels with high cold-ductility.

Basic principles for the top-blowing of iron with oxygen S. G. Afanas'ev, M. M. Shumov, and M. P. Kvitko (*Stal'*, 1960, (10), 884–892) The kinetics of top and bottom blowing are compared at length. With bottom blowing alone slag control is not possible as active slag is only formed at the end when C is low. In top-blowing, active lime slags can be obtained at any time and elements are oxidized in a different sequence. It is possible to obtain high-C and low-P together.

Development of a method and means for measuring liquid metal temperature during converter blowing N. M. Lapotyshkin (*Stal'*, 1960, (10), 899) A note from TsNIIChM. Equipment for raising and lowering an immersion thermocouple without affecting the process is said to have been developed.

Production of steel from basic iron in the converter by oxygen top blowing S. G. Afanas'ev (*Use of oxygen in metallurgy*, (Ed.) I. P. Bardin, *Metallurgizdat*, 1957, 31–40) Trials are reported in a 10-t converter; Russian melting practice on industrial scale, operation data, and results are reported, and details are given of the production of a pre-refined metal for the electric furnace, and of trials on the possibility of obtaining an intermediate product for the basic OH and electric furnaces.

Rennluppen and sponge iron as a cooling agent in oxygen top blowing E. Plöckinger and K. Borowski (*Techn. Mitt. Krupp*, 1960, **18**, Aug., 1–8) The effects of cooling additions in the oxygen process are reviewed, and investigations on the use of Rennluppen and sponge iron as cooling agents in the LD process are described, and the results evaluated and compared with those obtained with normal scrap additions.

Notes on gas-flow pattern through the regenerative chambers of open-hearth furnaces L. G. Septier (*JISI*, 1961, **197**, March, 215–222) [This issue].

Desulphurization in a side-blown basic vortex drum converter (*Iron and Steel (China)*, 1958, (13), 19; from *Sci. Abs. China, Techn. Sci.*, 1959, (1), 59) An investigational report with operational data from 20 heats is presented and discussed. 75% S is removed as volatiles and the rest in slag. FeO content and basicity for optimum operation are considered.

Properties of plain and alloy steel produced by the LD process S. Ammareller and W. Knorr (*Stahl Eisen*, 1960, **80**, Oct. 13, 1417–1423) This is an appraisal of the suitability of the LD converter to replace an OH furnace. The OH furnace was used to produce a variety of very different types of steels by the pig iron-ore process, and was replaced by a LD converter. In a very short time it produced steels that were at least equal in quality and in some instances (such as plain steel strip and sheet) definitely superior to those from the OH furnace. The quality of alloy steels, too, was excellent although the C content is limited to about 1%. The purity of the LD steels, i.e. the absence of non-metallic inclusions, is greater than in the OH steels. The very low level of metallic impurities and particularly of hydrogen of the LD steels is another important advantage.—T.G.

Preparation of converter bottoms on a base of kaolin waste A. A. Tol'skii and A. R. Bazilevskii (*Ogneupory*, 1960, (8), 357–359) At the Bessemer shop of the Enakiev Metallurgical works, steel is melted in converters bottom blown through 18 tuyeres. The components of the ramming mass are mixed and crushed; they are quartzite, kaolin waste, kaolin, and coke fines. Quartzite is also partly or completely replaced by kaolin waste. The mass is rammed by pneumatic hammers working at 5–6 atm in 50–60 mm thick layers. The depth of the bottom lining reaches 710 mm.

Unfired converter bottoms in the Thomas plant of the Seraing Steelworks, Belgium R. Schuermans, J. Van Neste, and P. Nève (*Silicates Ind.*, 1960, **25**, July–Aug., 341–346) Experience with the use of unfired bottoms since 1954 is discussed, and their design and construction are considered. They are shown to be more readily repaired, to have a longer life, and to be more economical in use and construction than conventional converter bottoms.

'Cupola converter' steel process Acme Steel Co. (*Iron Coal Trades Rev.*, 1960, **181**, Sept. 30, 735–736) The cupolas and LD vessels are described, also the soaking pit and rolling systems.

Cupola-converter, process produces ingots at Acme (*Steel*, 1960, **146**, May 2, 74–76) An installation of two cupolas and two converters is described which produces steel in the following stages. Cupolas are charged with scrap, cold pig and cast iron, coke, and flux blown with preheated air. Molten iron flows continuously into a gas-heated holding furnace. The holding furnace tilts to fill a ladle which charges the converters. 25–60 t heats are oxygen-blown in about 20 min. The steel is cast into ingots for rolling into strip products.

A study of the technical and economic factors of the converter process using oxygen and the open hearth process N. M. Lapotyshkin (*Stal'*, 1960, (10), 899) A note from TsNIIChM. Savings of 40–50 roubles/t on capital investment and of 10–15 roubles/t compared with the OH are claimed.

Expansion of Inland's No.3 open hearth shop R. G. Phelps (*Iron Steel Eng.*, 1960, **37**, June, 105–110) The design of the three additional OH furnaces installed, and materials handling and casting facilities are described.

The first campaign of the open hearth furnace at the Bhilai steel works M. E. Savos'kin (*Stal'*, 1960, (10), 898–899).

The use of dimensional analysis in the design of recuperator models for the study of thermal problems R. Kremer (*Sbornik (Ostrava)*, 1960, **6**, (2), 151–158) [In Czech] Criteria determining the design of recuperator models, for the study of heat transfer process by similarity theory, are derived and discussed.—P.F.

Reply to A. D. Kiyuchenko's article 'Comparative method of assessing the operation of the ports in OH furnaces' M. A. Glinkov (*Izvest. VUZ Chern. Met.*, 1959, (8), 179–181) The original article appeared in this journal (1959, (1), 91–96). It suggests a comparative analysis based on the operation of the ports, when these are not working under exactly similar conditions, which could serve for constructing operational diagrams. This contention

is opposed in the present article because of the non-uniformity of the heat transfer along the length of the bath which can be removed only by constructing new types of furnaces. Klyuchkov replies to these remarks (181–183) by pointing out that both in the laboratory and in industrial research his collaborators are paying the greatest attention to the gas mixtures not only as a measure of increasing heat capacity but also as a means of intensifying production.

Forsterite refractories of Khabozersk olivine and their use in OH furnace regenerator checkers E. P. Markevich (*Ogneupory*, 1960, (8), 363–367) Forsterite bricks of Khabozersk olivine are highly compact, are strong and resist high temp. In the OH furnace regenerators forsterite brick checkers have proved to have a sufficient service life and to be resistant to the action of molten dust. Best results have been obtained with this material in the checkers of the air regenerators.

Structural changes in magnesite–concrete blocks in OH furnaces A. A. Pirogov, E. N. Leve, and P. D. Pyatikop (*Ogneupory*, 1960, (6), 260–266) Tests have shown that structural changes occur in two opposite directions; the shrinkage of the periclase cement and the growth in the volume of the grains because of the formation of spinel. This compensates for the shrinkage and inhibits the sintering of the concrete. The result of these two processes cancel out and the volume of the magnesite–concrete blocks in the linings of the OH furnaces remains constant.

Testing new refractory materials to improve open hearth operation G. A. Khasin and U. N. Davidyuk (*Stal'*, 1960, (9), 808) A note from Zlatoust. Use of silico–chromite brick and D2 grade fireclay in the checkers is noted. Conversion to double staggered type raises preheat temp. from 960–1060°C.

On the construction and reconstruction of No.4 basic open hearth furnace S. Takizawa (*Nisshin Seiko Giho*, 1959, Dec., 19–28) This note describes the construction of no.4 fixed basic OH furnace of 100 t capacity designed by Loftus Engineering Co., USA. Subsequently the oxygen process and coke breeze additions were introduced and the furnace was replaced by a Mertz type with a single uptake, resulting in an increase in productivity from 11·8 to 13·8 t/h.

On hydrogen in steels made in basic gas and oil-fired open-hearth furnaces M. Šicha (*Hutn. Listy*, 1960, **15**, (8), 657–670) Factors affecting the H_2 content of steels made in large basic furnaces, either by the 'ore' process or by the 'scrap' process, were investigated, and methods for minimizing the H_2 contents are listed.

Manufacture and application of MgO–Al_2O_3 bricks in open hearth furnace roofs (*Iron & Steel* (*China*), 1958, (9), 19–24; from *Sci. Abs. China, Techn. Sci.*, 1959, (1), 51) The technology and manufacturing process of magnesia–alumina bricks with their physical properties are described and compared with the life of magnesia–chrome bricks. Data and appropriate tables are attached.

Lance mixes fuel and oxygen to boost steel production C. L. Kobrin (*Iron Age*, 1960, **186**, July 28, 75–77) Various uses for the new oxy-fuel lance are described with some results, and the story behind its development is given.

The distribution of pressure in the open-hearth furnace V. Parma (*Sbornik* (*Ostrava*), 1960, **6**, (2), 137–150) [In Czech] On the basis of measurements carried out on a 200-t furnace it is suggested that the tapping point for impulses used to control the pressure in the furnace should be in the geometrical centre of the roof, as it is there influenced least by the direction of the flame. Draught and pressure histograms were obtained over entire runs, measurements being made at various points of the entry and exit ends of the furnace. Specific suggestions for a more rational control of furnace performance are made.—P.F.

Casting pit practice: Exothermic hot tops J. R. Wynne (*Iron Coal Trades Rev.*, 1960, **181**, Aug. 19, 405–408) A new type of exothermic hot top now in standard use at Corby and its method of operation is described. **The use of C & D hot tops** W. A. Jenks (406–409) The C & D hot top in use at Irlam and its operation, with rolling and metallurgical quality of ingots and billets are described. **Some notes on Vallak hot-top practice at Consett Iron Co. Ltd** S. G. Cope and C. Lonie (409–410, 412) The advantages resulting from the use of Swedish-type Vallak tiles at Consett are described.—S.H.-S.

How new hot-top technique cuts steelmaking costs D. E. Grimme and D. K. Matthews (*Iron Age*, 1960, **185**, May 26, 97–99) The preparation and use of 'tiger' hot-tops are described. The top, made of sand, is formed in a mould on the top of each ingot mould, and set by the CO_2 gassing method; it is then ready for use. It is used for ingot sizes between 48×17 and 90×40 in. The tops are rapidly made and, except for the largest sizes do not need steel straps. Metal yields have been increased, and the volume of steel in the hot top has been decreased by 1–2% compared with cement tops.—D.L.C.P.

Stoppers and nozzle linings for steel pouring, made from Ural raw material A. A. Berezhnaya A. M. Prokop'eva, and G. N. Batueva (*Ogneupory*, 1960, (3), 107–108) Stoppers and nozzle linings made with this raw material have a compact structure and are resistant up to 1710–1730°, with a 21–23% porosity. The chemical composition is 56·3–58·0%SiO_2; 35·6–38·0%Al_2O_3; 1·8–2·3%Fe_2O_3, and 0·7–0·8%CaO.

Study of the hydrodynamics of molten steel in tapping and teeming. III. On the stability of the molten iron jet through various shapes of nozzles F. Koike, Y. Muto, and S. Okubo (*Tetsu to Hagane*, 1960, **46**, May, 556–560) With 20 mm dia. nozzles (normal and tapered), jet conditions were not turbulent at a head of 900 mm. With 40 mm dia. nozzles, jets through tapered nozzles were not turbulent at 900 mm head, but those through normal nozzles were turbulent at heads above 700–750 mm. Extrapolation from mercury-jet results indicate entrainment of bubbles at ~600 mm head.

Investigation of the strength of steel ladles and procedures for calculating them I. M. Makeev (*Stal'*, 1960, (9), 799–803) Models of one-fifth scale in metal and one-twentieth scale in plastic were used and equations are developed showing that ladles can be made much lighter. The new designs are shown.

Lightweight design steel ladles I. I. Dobroskok, M. Ya. Brovman, L. P. Kur'yanov, and E. V. Surin (*Stal'*, 1960, (9), 806–807) A 220-t ladle weighing only 24·5 t is described. 275 and 380 t ladles will be designed.

The casting nozzle, runner system A. Mal (*Fond. Belge*, 1960, **30**, July–Aug., 198–201) The writer describes the analyses of the system from the point of view of securing the best possible results in an ordinary furnace, a nodular iron furnace and a steel furnace.

Compound nozzles for pouring rimming steels in a unit for continuous casting G. V. Kukolev, V. M. Strelets, N. V. Pitak, and T. A. Amerikova (*Ogneupory*, 1960, (8), 352–346) The nozzles are made of porous chamotte (the weight-bearing part) and of a highly aluminous magnesite or zircona lining (the operational part). Such nozzles have given longer service than other linings.

Production of stainless slabs at the continuous casting plant of Schoeller–Bleckmann Stahlwerke AG, B. Matuschka (*JISI*, 1961, **197**, March, 189–198) [This issue].

Continuous casting of steel at Charleroi G. A. Homes (*Hainaoult, Special issue of Agence Économique et Financière*, 1959, Nov. 7, 21–23) This article lists the advantages of continuous casting and then reviews the development of the process in Belgium. A description is given of the experimental continuous casting installation of the Centre National de Recherches Métallurgiques at the Acieries et Minières de la Sambre which cast its first billet in Dec. 1957. Success has been achieved in continuous casting even rimming basic Bessemer steel. Examination of the continuously cast steels has not yet been completed.

Service life of stoppers in continuous steel casting V. M. Strelets and N. V. Pitak (*Ogneupory*, 1960, (2), 64–69) Fireclay stoppers containing 5, 10, and 15% graphite are distinguished from normal fireclay stoppers by their high heat resistance, heat conductivity, and long service life. Increasing the graphite proportion from 5 to 15% (to increase the rigidity of the stoppers) when used with magnesite linings promoted longitudinal cracks. For best service in continuous steel casting, the tundish should be heated to 1300° and the stoppers air cooled.

Locating the crystallization front in a continuously cast ingot A. N. Maslov and V. E. Neimark (*Stal'*, 1960, (9), 797–799) A simple method of adding ampoules of Cu or Al foil containing FeS and detecting the front after solidification by means of Baumann S prints is described. The results agree with the findings from previous methods. Depth of pipe could not be measured but it is supposed that the use of sheet iron ampoules would make this possible.

A comparison of the quality of semi-continuous cast and conventional ingots of 1Kh18N9T steel Yu. E. Kan, E. P. Matevosyan and B. Z. Kononov (*Stal'*, 1960, (9), 846–849) Macrostructures are essentially the same but the semi-continuous casting has an ill-defined skin zone about 5 mm thick and the crystals are somewhat less in cross-section. α-Phase is finer grained and more uniform in distribution and gaseous inclusions are also more regularly distributed. Surface defects penetrate more deeply than in normal ingots.

On the solidification of ingot feeder heads S. Maruhashi (*Nisshin Seiko Giho*, 1959, Dec., 11–18) This paper discusses the depth of the primary pipe observed at the feeder head of killed steel ingots, the volume of the mould, ingot solidification time, average dia. of the hot top., solidification constant, shrinkage of the steel, and the thermal properties of hot-top materials. From theoretical observations the writer draws some conclusions which account for some phenomena which appeared during the freezing of the ingot feeder head.

On the shrinkage cavity of small size steel ingots Shei Chia-lan (*J. Pekin Inst. Iron Steel*, 1958, (5), 33; from *Sci. Abs. China, Techn. Sci.*, 1959, (1), 43) Excessive shrinkage cavity is corrected by raising the height of the centre runner and covering the top of mould. Cross-sections of runner brick and the centre runner should facilitate rapid cooling of metal in the mould, while, cooling in the runner brick and centre runner proceeds as slowly as possible. A reducing atmosphere is maintained in the mould during the operation.

Correction of the defect of 'end blow hole' in small scale open hearth rimming steel ingots with low carbon content (*Iron & Steel* (*China*), 1958, (5), 16–20; from *Sci. Abs. China, Techn. Sci.*, 1959, (1), 44) Tests have been made to discover the cause of the cavity in the pouring gate of the steel ingot. Addition of Al during pouring is recommended and the effect of rolling and adding Al on the ingot has been studied.

PRODUCTION OF FERRO-ALLOYS

Production of silicomanganese V. P. Elyutin, Yu. A. Pavlov, B. E. Levin, and E. M. Alekseev (*The production of ferroalloys*, 1957, Chap. III, Sect. 5, 124–128) Grades of Si–Mn produced in the USSR, their applications, methods of production and economic factors are reviewed.

Reducing the cost of production of ferrosilicon in electric furnaces Ya. S. Shchedrovitskii and Yu. S. Maksimov (*Stal'*, 1960, (10), 911–914) The economics of production are considered and recommendations are made for expanding production in regions of cheap electric power and by replacing obsolescent transformers. Automatic charging and other changes are also suggested.

FOUNDRY PRACTICE

The influence of foundry iron not directly smelted in blast furnaces P. V. Chernogorov and A. V. Bobrov (*Lit. Proizv.*, 1960, (7), 9–12) Blast-furnace foundry irons of the same type vary in different works and at different times according to the ores used etc. so that when remelted in foundries the castings are not uniform. The article considers the manner in which these irons are remelted in a number of individual foundries.

Standardization of the quality of cast surfaces Ya. G. Polyakov (*Lit. Proizv.*, 1960, (7), 44–46) The methods of assessing the smoothness of a cast surface are not standardized. The position

in the USA and Czechoslovakia is discussed. Efforts are to continue in 1960 and 1961 to endeavour to bring about a general standard by co-operation among all foundries.

Loss of alloy elements by oxidation when melting steel in induction furnaces V. A. Shakhnovich (*Lit. Proizv.*, 1960, (7), 39) A list is given of the percentage losses of the alloy elements from Fe–W, Fe–Cr, Fe–V, Fe–Ti, Fe–Mn, Fe–Si, Fe–Nb, Si–Zr, and carbon, both in the iron and as coke in the charge.

Crucibles of heat-resistant concrete for induction furnaces V. S. Sasss (*Lit. Proizv.*, 1960, (7), 42–43) Tests have been carried out by the Concrete and Reinforced Concrete Institute for Construction and Architecture. The raw material that goes into one m^3 of concrete consists of 300–350 kg waterglass (1·36–1·38); 18–21 kg industrial Na_2SiF_6; 550 kg finely crushed magnesite; 500 kg chamotte sand, and 800 kg chamotte rubble. The method of preparation and experimental results are given.

Casting with accurate dimensions L. Kálmán (*Koh. Lapok-Öntöde*, 1960, **11,** May, 100–105) In order to produce castings with accurate dimensions, adequate design as well as application of some suitable method, such as pressure die-casting, precision investment casting, die casting, shell moulding, CO_2+waterglass moulding, cement moulding, or mechanized green-sand moulding, is necessary.—P.K.

ASTM changes grey iron spec. to include section size (*Mat. Des. Eng.*, 1960, **52,** Aug., 10–11) A discussion of changes in A48 with tables.

Modifying the structure of cast iron by additions of tin W. E. Hoare (*Tin*. 1959, Summer, 4–8) This article describes a study of the effects of Sn in cast iron. It is concluded that the addition of small quantities to cast irons suppresses ferrite and promotes pearlite instead, tending to cause the formation of massive cementite. Thus, structures can be produced possessing wear resistance and good machinability. Possible applications are in the manufacture of items such as piston rings, cylinders, machine tool components, crankshafts, rolls, and so forth. There is some evidence to suggest that Sn may be a stabilizer as well as a promotor of pearlite.

More notes on structural changes in iron caused by additions of tin (*Fonderia*, 1960, **9,** July, 324–325) This short note summarizes recent research which confirms that the addition of small quantities of tin to ordinary nodular irons is an economical and reliable method of obtaining iron free from ferrite.

On the practice of high-silicon iron casting I. M. Yazovskikh and V. A. Lesh (*Lit. Proizv.*, 1960, (7), 41–42) According to GOST 2233–43 Fe–Si contains 14·5–16·0%Si, 0·5–0·8%C; 0·30–0·80%Mn; less than 0·1%P and less than 0·07%S. This alloy is highly resistant to most acids and salts. Description is here given of the protracted investigations at the Sverdlovsk Pump manufacturing works to overcome the large proportion of rejects when casting components of this alloy and the changes in the technology of casting which have considerably reduced the proportion of rejects.

The effect of overheating when melting and inoculating, on the properties of sulphur cast iron N. G. Girshovich (*Lit. Proizv.*, 1960, (7), 26–32) The conclusions reached after extensive experiments suggest that each separate case has its optimum overheating and inoculation temp. and that further investigations in this respect are called for. It may be said, however, that considering the differences of the materials with coarse graphite in the charge, that a much higher temp. of overheating is necessary when melting in the cupola than under other conditions or when melting in an electric furnace.

Crystallization of cast iron treated with strontium A. V. Chernovol (*Metallov. Obra. Met.*, 1959, (2), 37–39) Two heats, one of eutectic composition containing 0·068%Sr, the other hypoeutectic with 0·072%Sr were made. It was shown that the addition of 0·8%Sr did not produce nodular graphite, and therefore Sr cannot be substituted for Mg as an inoculant.

Study of the production of pig iron suitable for the production of spheroidal iron T. Kinoshita and S. Sano (*Fond. Ital.*, 1960, **9,** July–Aug., 297–311) The authors describe the difficulties met with in Japan in producing iron suitable for making spheroidal iron. After tests which they describe, the authors succeeded in producing raw material for spheroidal iron containing only a small amount of impurity and low gas content by melting steel scrap with a lower impurity content than iron in a basic electric furnace in a perfect reduction atmosphere decarburizing and deoxidizing with coal dust. The costs were much lower than that obtained using charcoal or special iron in pigs and the spheroidal iron produced was equal in quality to iron in Swedish pigs.

The effect of ferrosilicon inoculation on the formation of spheroidal graphite in iron J. Piaskowski (*Studii si Cercetari Met.*, 1960, **5,** (1), 7–27) Investigations carried out on Mg iron regarding structure, form, and distribution of graphite inclusions have shown that inoculation of this iron with Fe–Si results in an increase in the spheroidal graphite crystallization nuclei as well as in the density of this distribution. The effect is explained by its action on the structure as a result of the cooling rate.

Alloying s.g. iron E. E. Farafonov and L. P. Gorushkina (*Lit. Proizv.*, 1960, (7), 24–26) This is a study of the physical and mechanical properties of s.g. iron when alloyed with Cu, Cr, Ni, and Mo. Alloying sulphur-containing iron results in an appreciable refinement of the graphite structure and of the metal matrix which slightly increases UTS and hardness. The detailed effect of each of these metals is considered individually.

Observations regarding the siliconizing of s.g. irons T. Dumitrescu (*Studii si Cercetari Met.*, 1960, **5,** (1), 29–49) Investigations regarding siliconizing in solid media justify, *inter alia*, the following conclusions. The hardened silicon skin gives good results as regards adherence, compactness, and strength in inoculated s.g. irons, is less satisfactory in inoculated lamellar graphite irons with low sulphur content, and gives unsatisfactory results in the usual grey irons owing to their high sulphur content. The optimum composition of the cementation medium consist of 40%Fe–Si of the 75%Si quality. 60% chamotte and 1%NH_4Cl. The depth of the layer increases rapidly up to 6 h heating and then more slowly during longer periods.

The siliconizing of s.g. irons T. Dumitrescu (*Rev. Roumaine Met.*, 1960, **5,** (1), 5–23) [In English] The siliconizing was carried out in an electric furnace with silite rods in closed boxes. Heating lasted about 4 h and cooling about 12 (down to 200°C). Tables are given for the chemical compositions of the irons, of the observed effects of temp. on the thickness of the siliconized skin, the structure of the hardened case, tensile strength, elongation, and resistance to oxidation and to acid corrosion.

The effect of the ratio of sulphur to manganese on the shape of graphite in malleable cast iron E. Fülöp (*Koh. Lapok Öntöde*, 1960, **11,** May, 112–118; June, 133–137) An increasing sulphur content not only hinders graphitization, but also produces nodular graphite, instead of the usual lumps and flakes, when the ratio of S to Mn is equal to, or higher than 1·1. Simultaneously, traces of cementite due to the effect of iron sulphide have been discovered in the structure.—P.K.

Coalescence of graphite in malleable iron O. M. Galemina (*Doklady Nauch. Vyssh. Shkoly-Metall.*, 1959, Jan–March, 168–169) The iron investigated contained 2·32%C, 0·22%Mn, 1·09%Si, 0·04%P, 0·0041%S, and 0·05%Cr. Specimens were graphitized at 950°C followed by heating at 1050°C for 10 h. Appreciable coalescence occurred, and the number of graphite inclusions were decreased by a large factor as a result of coalescence. The mechanism of coalescence is discussed.

Producing sound malleable iron test bars C. T. Moore (*BCIRA J., Res. Dev.*, 1960, **8,** May, 398–400) The properties of malleable iron test bars are significantly affected by porosity. A method for ensuring the soundness of test bars has been developed at BCIRA. The recommended design of the casting is illustrated and supported by typical results.

The partition of alloying elements in malleable irons G. Sandoz (*NRL*–5268, 1958, Dec., pp.28; from *Nucl. Sci. Abs.*, 1960, **13,** June 30, 1503) The findings of significant amounts of every alloying element investigated in the cementite phase suggests that the mechanism by which alloying elements influence graphitization kinetics may involve a change in the thermodynamic stability of this phase.

Progress in steel casting R. Frąckiewicz (*Prz. Techn.*, 1960, **81,** (18), 15–16) The author describes three new processes introduced into Poland in 1959; the use of exothermic substances giving an 11% production increase and the manufacture of railway rails which are to be subjected to excessive impact loading from Hadfield steel containing 17%Mn.

Investigations into the activation of bentonite clay from Gorki near Pinczow G. Szreniawski and J. Owczarek (*Prz. Odlewn.*, 1960, **10,** (7–8), 194–202) The results of the investigation are given. The aim was to define the influence of different activators on the binding properties of the clay. Two types of investigation were carried out. The first was based on investigation in the field of physical and chemical phenomena. The second on the measurement of technological properties of the sands activated with clay as binder. The first investigation gave the explanation to the essentials of the phenomena occurring during activation, facilitated the selection of the most suitable activator, and established approximately the conditions of carrying out the activation. The second investigation established the final effects of activation.

Moulding practice: ladle lining for cast iron J. Lamoureux (*Fond. Belge*, 1960, **9,** Sept., 231–233) Materials and methods used for lining ladles of 20 kg to 4 t and of 5 to 10 t capacity are given.—R.P.

New anti-burn moulding mixture R. G. Gurarii (*Lit. Proizv.*, 1960, (7), 37) The mixture consists of 53–63% Millerovo and 33–43% Vodolazh sand; 0–3% fireclay; 0–1% wood flour or DP binder; 1%NaOH (30%) solution; and 4–5% waterglass (sp.gr. 1·48–1·52). This mixture has been in use since 1958 for castings of from 0·3 to 5000 kg with wall thicknesses from 7 to 200 mm, and has given satisfactory results.

Iron castings of increased precision in semi-permanent moulds A. N. Antonov (*Lit. Proizv.*, 1960, (7), 1–5) At the Roshal' works the entire casting equipment has been modernized and as a result the excess metal for machining has been reduced by, on an average, 5 mm resulting in a saving of over 300 t of metal yearly. A description is given of the casting in semi-permanent moulds, of drums, drying cylinders, pressing rollers, and conical rotors for paper and textile machinery. The composition of the moulding mixtures and the methods of preparation also of the protective coatings are the same. Details are given for each separate component.

Experience in casting V-shaped cylinder blocks A. A. Lamsaov (*Lit. Proizv.*, 1960, (7), 8–9) New types of heavy lorries are now manufactured at the Likhachev Moscow Motor works. The V-shaped cylinder block now has eight cylinders placed at an angle of 120°. The block is moulded on the conveyor used for rectangular blocks. A detailed description of moulding and casting is given.

Casting high quality large iron components B. V. Knorre (*Lit. Proizv.*, 1960, (7), 6–8) To avoid cracks which occur in casting large components, coolers must be introduced to reduce thermal stresses. These are placed chessboard fashion inside the mould at distances of about 20–30 mm from the zone exposed to these cracks. The hardness of cooled castings after mechanical treatment increases by 10–20 Brinell units. Individual arrangements of sprues and of the pouring systems are also suggested.

Cast-to-shape tool steels gain favour with industry F. C. Shields (*Iron Age*, 1960, **185,** April 28, 104–105) The advantages of cast-to-shape blanks over forgings for tools, dies, rolls, and machine parts are explained. They are lower blank-production cost; lower material cost; less machining to size; high compressive strength. Impact resistance and tensile strength may be lower. Special high and low alloy grades of casting metal are available.

Casting of 'Cameron Chambers' G. Say (*Koh. Lapok-Öntöde*, 1960 **11**, July, 151–156) Hungarian experience on the design, moulding, and casting of 'Cameron Chambers' used in the oil industry are reported in the paper.—P.K.

Casting from iron moulds in the U.S.A. P. Januszewicz (*Prz. Odlewn.*, 1960, **10**, (7–8), 221–225) The article comes directly from a paper by L. L. Zinsmeister and R. A. Wilde in *Eaton Engineering Forum*, 1956, **17**, Oct. The author describes the process in detail, pointing out that for a long run the method is economical giving in addition high dimensional accuracy and good finish.

Two-layer cylinder jacket for a tractor, cast centrifugally in metallic moulds P. P. Luzan (*Lit. Proizv.*, 1960, (7), 43) At the Kiev Lepse works, tests have taken place on casting centrifugally two-layer cylinder jackets for the SMD–1 type tractor engine, into unlined metallic moulds. The external non-working layer of the jacket is cast of low sulphur iron and after 2–4 s the second portion of low-alloy type 8Ch 21–40 iron is poured in. The chemical composition of the two layers is tabulated together with that of the transition layer, 1–2 mm thick, which is formed. Hardness of the external layer is H_B 164–189 and of the internal layer 183–219. The structure of the external layer is highly dendritic and of the internal layer predominantly pearlitic.

The solidification of cast iron and the interpretation of results obtained from chilled test pieces H. Morrogh (*Brit. Found.*, 1960, **53**, May, 221–242) The influence of melting and pouring temp., inoculation and the charge on the properties, structure, and chilling characteristics of grey cast iron are discussed with reference to the mode of eutectic solidification and hypothetical cooling curves. The nature of the thermal effects involved in the casting of a chilled test piece and their effect on the nucleation and growth mechanism of solidification are considered.—A.D.H.

Progress in investment casting R. L. Wood (*Met. Rev.*, 1960, **5**, (17), 119–134) The major process advance since the original development of the investment casting process has been the development of the shell mould. The author concludes that shell moulds are well established and in the case of large castings have an inherent superiority over poured refractory moulds. In vacuum casting they have a bright future and for special applications such as turbine blades requiring a fine finish they have a secure position. Shell moulds have however certain disadvantages, e.g. control of mould temp. is difficult because the heat content of the thin shell changes rapidly.

Ceramic shell moulding gets boost R. R. Miller (*Steel*, 1960, **146**, May 9, 140–143) A process enabling polystyrene patterns to be used for ceramic shell castings is described. The patterns are made by machining, or injection moulding in steel dies, and may be made up into tree assemblies. The shell is formed by successive dippings of the pattern into a slurry and fluidized sand. Removal of the pattern has previously been impossible due to cracking of the shell, but patents are pending on a successful burnout procedure. The shell is re-heated prior to casting. Advantages are: backup often unnecessary; compared with wax, plastic is cheaper, stronger, and quicker to form; improved metal properties compared with flask type castings; flexibility of the process.

Ceramic shells solve problems on heavy complex castings Arwood Corp. (*Iron Age*, 1960, **186**, July 14, 102–104) A new process, yielding ceramic shell investment castings weighing up to 100 lb to serve in lieu of solid moulds, and in three alternate systems appropriate to different types of castings, is briefly described.—S.H.-S.

Shell moulded castings extend valve life Power Brake Equipment Co. (*Prec. Met. Mold.*, 1960, **18**, Aug., 64–65) The discs of a butterfly valve are now shell moulded of stainless steel 25–12.

Binders of epoxide resins L. D. Zeligman (*Lit. Proizv.*, 1960, (7), 37) Epoxide resin type Ed–6 is used for the preparation of cores of the I and II degrees of complexity and for moulds for iron, steel, and non-ferrous castings. It is prepared from 100 parts by weight of this resin at 120° mixed with 30 parts of phthalic anhydride (hardener), the liquid so obtained is mixed hot with sand moistened with 3–3·5% water. The percentage of moisture may be varied and a table is given of the corresponding properties of these mixtures.

A practical application of nucleation theory to soundness in iron castings J. D. Berry, J. M. Greenhill, and K. E. L. Nicholas (*BCIRA J. Res. Dev.*, 1960, **8**, May, 377–392) The causes of internal porosity in clutch plate castings produced in a foundry using an iron approximating Grade 17 BS 1452: 1956 were investigated. The first part of the article deals with the influence of ladle inoculation and pouring temp. and short-term practical recommendations made to overcome the problem of unsoundness in clutch plate castings. The second part describes an investigation into variations in the cupola operation and their effects on metal characteristics as a result of which changes were proposed in the cupola operation which would improve the overall soundness of foundry castings.

Studies on alloy white cast iron. V. Observations on the plastic deformation and cracks in white cast iron. VI. Bending and impact tests on various white cast irons I. Fukumoto (*Nippon Kinzoku*, 1959, **23**, May, 255–259; 259–262) V. Work on white and alloy white irons shows that, under tensile stress, cleavage cracks appear in the eutectic cementite and pass through the primary crystals or along boundaries. A more complicated mechanism under compression is described. The situations of slip lines and hair cracks are discussed. Tempered graphite and MnS particles have no relation to the cracks (14 refs). VI. The positions of hair cracks, transcrystalline cracks, and intercrystalline cracks resulting from bending and impact, and the variation of the stresses with C content of the alloys (hardness) are described. Fracture stress varied with S content, C content, melting conditions, casting conditions and heat-treatment.—K.E.J.

The harmful effects of lead in grey iron castings E. R. Evans (*BCIRA J. Res. Dev.* 1960, **8**, May, 340–342) Small amounts of lead can seriously reduce the strength of cast iron and may lead to premature failure. Loss of strength is attributed to the formation of spiky and Widmanstätten graphite. It is not yet possible to specify an absolute maximum safe lead content but recommendations are made on ways of reducing the danger of contamination.

New machine de-fins castings to boost foundry output R. H. Eshelman (*Iron Age*, 1960, **186**, July 21, 131–133) A completely mechanized installation automatically de-finning cored holes and recesses even in intricate castings, and eliminating chipping and snagging by hand, is described with details of design and operation.—S.H.-S.

Inspection and quality control in a foundry producing automobile and tractor castings J. W. Deaton (*Brit. Found.*, 1960, **53**, July, 325–329) The functions and administration of inspection and quality control in a foundry producing automobile and tractor castings weighing from 1 lb to 4½ cwt are considered.

The solidification of moulding mixtures with iron chips N. D. Egorkina (*Lit. Proizv.*, 1960, (7), 40–41) These semi-metallic mixtures with iron chips are used for speeding up crystallization. Their composition and thermal properties are generally known but their physical and mechanical properties less so. To study these, 14 compositions, differing only in the proportion of iron chip content, 1–3 mm particle size, and water glass as binder were investigated. With an increase in the proportion of iron chips in the mixture the compression strength diminishes in the wet condition but increases in the dry, reaching a maximum with a 55% proportion of iron chips.

Tests detect unsound castings Philadelphia Bronze & Brass Corp. (*Iron Age*, 1960, **185**, April 28, 111) Equipment for high pressure testing of castings is described. The parts are clamped on a table and tested hydraulically by an air-driven pump which can develop pressures up to 12 100 psi. Up to 30 simple castings per h can be tested.—D.L.C.F.

The application of the training of Soviet foundrymen to Hungary A. Vörös (*Koh. Lapok-Öntöde*, 1960, **11**, July, 145–150) The author describes the training of foundrymen in the USSR, and proposes some relevant changes in the Hungarian training system on the basis of Soviet experience.

Equipment for suction ventilation of foundries V. Hromádko (*Zváranie*, 1960, **9**, (9), 258–260) [In Czech] Various types of ventilators of recent Czechoslovak manufacture are shown and discussed.—P.F.

VACUUM METALLURGY

Vacuum metallurgy in the United States A. E. Franks (*Vacuum*, 1956–8, **6**, 59–74) A review, mainly of steel melting and treatment. Also low-carbon ferrochrome and carbide sintering are mentioned, and the steam degassing of steel.

Vacuum treatment of molten steel: A new way of improving converter steel production A. M. Samarin and L. M. Novik (*Vacuum*, 1959, **9**, May, 134–138) The chamber for treatment in the ladle at the Dzherzhinskii plant is shown and the process applied to Bessemer steel is described. Change in H_2 content and ingot structures are reported.

The theory and practice of vacuum melting O. Winkler (*Met. Rev.*, 1960, **5**, (17), 1–117) After expounding the principles of vacuum techniques the author gives a detailed review of current developments of the process including vacuum melting in the electron bombardment furnace, the vacuum induction melting process, and vacuum arc melting.

Rollmaker adopts vacuum degassing (*Steel*, 1960, **147**, July 25, 130) The entire output of hardened steel rolls of the Bethlehem Steel Co. is now being made from vacuum cast ingots in place of air cast ingots, with reduced H_2 content throughout the ingot cross-section. The process and testing are briefly described.

How vacuum melting stacks up D. C. Ludwigson and F. R. Morral (*Steel*, 1960, **147**, July 11, 95) A brief summary of the advantages of vacuum as against air melted steels and alloys.—S.H.-S.

Effect of vacuum melting on the mechanical properties of cast iron. Report No.2 M. Kikuchi and I. Iitaka (*Imono*, 1958, **30**, (4), 231–232) Charcoal, blast-furnace, and synthetic pig irons were melted under vacuum in graphite crucibles; tensile strengths of irons poured in air, vacuum, N_2 and A are compared, the amount of N_2 absorbed by molten iron during vacuum treatment and fractures obtained are reported and discussed, and the effects of impurities and the effect on undercooling are examined.

Effect of vacuum treatment on properties of steel O. F. Antropov, Yu. G. Gurevich, and E. D. Mokhir (*Izvest. VUZ Chernya Met.*, 1958, Dec., 17–20) 65-lb steel heats were (a) remelted in a vacuum, poured in air, (b) remelted and poured in a vacuum, (c) remelted and poured in air, but held in vacuum for 15 min before pouring. The effect of these procedures on H_2, N_2, and O_2 contents, number and length of hairline cracks, mechanical properties and non-metallic inclusions was examined.

Three vacuum processes being utilized to produce steels with superior qualities (*Ind. Heat.*, 1960, **27**, April, 776–778) Brief details are given of the principles of vacuum induction melting, consumable arc melting, and vacuum stream degassing (of metal between ladle and mould), and of applications for vacuum-treated steels.—K.E.J.

Experiments and thermodynamic considerations on desulphurization of Fe–S and Fe–C–S alloys in vacuum melting. I R. Ohno (*Nippon Kinzoku*, 1959, **23**, Aug., 489–493) With Fe–C–S alloys, the rate in an Al_2O_3 crucible is initially lower than in a graphite crucible, but increases with time and gives a lower final S concentration. This is caused by Si entering the melts. The S content decreases with increasing temp.; and should decrease with increase of C concentration (11 refs). **Experiments and thermodynamic considerations on the desulphurization of Fe–Si–S and Fe–C–Si–S alloys in vacuum melting. II** (493–497) By comparison with Fe–C–S alloys, the desulphurization velocity is greater and the min. S concentration is lower. Desulphurization and decrease of Si

occur simultaneously, and the S concentration attained decreases with increase of Si concentration. The S concentration attained at 1700° is less than that at 1600°C. Results are interpreted in terms of the equation $Si + S \rightarrow SiS(g)$ (13 refs).—K.E.J.

Improvement of Cr–Ni–Mo iron base alloys by vacuum melting and castings F. J. Gillig (*CAL–KA–1289–M–5*, 1959, Sept., pp.16; from *Nucl. Sci. Abs.*, 1960, **14**, June 15, 1366) Effects of minor changes in composition and vacuum melting on the high temp. mechanical properties of iron and base alloys containing 20Cr–20Ni–5Mo, and various minor additions of Nb, W, Ti, B, and Al were investigated in 21 heats with various compositions, the 100-h rupture strength at 1500°F being used as the basis for rating the elevated temp. strength. The strength of the base line heat was not surpassed by any appreciable amount but equivalent strengths were obtained with several compositions which were leaner in alloying elements.—S.H.–S.

Investment casting in vacuum L. S. Taylor (*Found. Trade J.*, 1960, **109**, Oct. 6, 419–427) Practice by G. L. Willan Ltd is described and illustrated. Equipment and operation, advantages of the process and trends are discussed, mainly for Ni-base alloys.

Deoxidation of iron by fusion under vacuum P. Turillon (*Rev. Mét. Mém. Sci.*, 1960, **57**, Sept., 649–658) An experimental study of the deoxidation of pure iron by vacuum induction melting. It is shown that a kinetic equilibrium exists between deoxidation and reoxidation from the crucible materials, at the stage where the concentrations of C and O_2 are at a minimum (C = 0·006% and O_2 = 0·0012%) (14 refs).

Mathematical analysis of the degassing of specimens held under vacuum at constant temperature J. Calmettes, J. Bertin, and P. Bastien (*Rev. Mét. Mém. Sci.*, 1960, **57**, Sept., 659–675) In the first part of the paper the degassing law $\log p - Kt$ is derived from Fick's Law for a steel specimen kept at a constant temp. after the H_2 contained in it is completely in the interstitial condition in the iron lattice. The law is established for specimens where the H_2 exists in the interstitial condition, entrapped in the lattice imperfections and as molecular H_2 of the microcavities.

REHEATING FURNACES AND SOAKING PITS

Design and operation of modern soaking pit plants K. F. C. Skroch (*Neue Hütte*, 1960, **5**, Aug., 451–464) Construction and operation of modern one- and two-way fired soaking pits are described in detail, and the utilization of waste-heat by ceramic and metal recuperators, together with the use of measuring and control equipment are reviewed.

Soaking pits keep pace with Kaiser expansion M. L. Gruver (*Steel*, 1960, **147**, Aug. 15, 88) The superintendent of the Fontana Cal. plant of Kaiser Steel Corp. describes the increased size and number of the soaking pits built or rebuilt to cope with steadily increasing melting and rolling capacity. Numbers and sizes are specified.—S.H.–S.

Converters may spur use of electric soaking pits Rust Furnace Co. (*Steel*, 1960, **146**, May 23, 138–140) The design and application of 'Elpit' electric soaking pits is described. The pits are divided into cells for one or more ingots, each cell having a cover. The resistance heating elements are coke-filled silicon carbide troughs running lengthwise in the pits. There are four basic types of pits with different arrangements of ingots and resistors. Advantages are: low capital cost and space requirements; rapid loading and unloading with little interference with other ingots; good control of atmosphere and temp. They are particularly useful in converter practice where teeming is frequent and for special steels. Power consumption in a pit charged with hot ingots with short track times is about 22 kWh per t. Installations have been made in Europe and America, including Consett Iron Co. Ltd.—D.L.C.P.

Ingot temperature control in soaking pits L. Tomis (*Hutn. Listy*, 1960, **15**, (7), 506–510) Control of the thermal regime of soaking pits is possible by various methods, e.g. depending upon measurements of ingot surface temp., measurements of the heat flow by means of calorimeters, placed between ingot and furnace wall, and by empirical methods utilizing measurements of heat transfer in the furnace and above the recuperators. The last-named, although theoretically least exact, appears to be most practicable and inexpensive.—P.F.

The comparison of small forge-furnaces D. Dioszeghy, J. Dojcsak, I. Pentek, and O. Farkas (*Koh. Lapok-Öntöde*, 1960, **93**, May, 226–231; June, 283–286) The authors compare the operational data of two small recuperative forge-furnaces, one is a reverberatory U furnace, the other has permeable walls. The time for heating-up the latter is much less than for heating-up the former. The latter is therefore more suitable for intermittent operation and uniform heating than the former.—P.F.

An analysis of the output of forging furnaces P. Bukowski (*Obrobka Plast*, 1959, **1**, (3), 101–118) The thermal output of a modern furnace is analysed and the utilization is outlined in relation to batch, pusher, and rotary hearth type furnaces. The relationships obtained give furnace output with a given charge as well as optimum hearth dimensions. In addition, the formulae allow a standard to be set for existing furnaces. In conclusion the performances of the various furnaces are compared on the basis of charge form and temp. distribution.

Thermal problems of induction billet heating. I, II, R. M. Baker (*Ind. Heat.*, 1960, **27**, May, 956–964; June, 1193–1200) The application of equations from classical heat-flow theory to induction heating of cylindrical (or substantially cylindrical) billets is described in detail. Aspects covered are a cylinder supplied with constant power density through the surface, temp. equalization in a cylinder, and the induction-heated cylinder. Further equations are developed from the theoretical models considered. These equations deal with the practical heating requirements of billets for delivery to the press, and with the complication of non-uniform rate of heating.—K.E.J.

The evolution of stock and heat treatment furnaces for drop forgings C. G. W. Betts (*J. Inst. Prod. Eng.*, 1960, **39**, June, 365–375) The author traces the development of furnace technology describing the various fuels used the factors making for gradual modification of furnaces, and present-day standards of furnace technology with special reference to present design and future trends in design and control.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Heat treatment of iron. I (*Fonderia*, 1960, **9**, Aug., 337–345) This first part deals with ordinary and special irons. The author first discussed the general question of elimination of tensions, then annealing, methods of increasing tensile strength and wear resistance, flame hardening, surface hardening of iron castings by induction reheating, hardening by salt bath treatment, and finally austempering and martempering.

Developments in heat treatment (*Mech. World*, 1960, **140**, 249–250) A brief review of discoveries made and research attempted in the heat-treatment of steels since 1939, in a series of short notes.—S.H.–S.

The scientific basis of the heat treatment of steel in relation to practical applications A. Constant (*Rev. Mét.*, 1960, **57**, Aug., 695–713) A number of well-established general results can be used in practice, and are reviewed. Austenite transformation curves and their practical applications are studied (29 refs).

Heat treatment of high-strength steel for airframe applications R. J. Florentino, D. B. Roach, and A. M. Hall (*DMIC–119, PB* 151076, 1959, Nov., pp.106; from *Nucl. Sci. Abs.*, 1960, **14**, April 15, 839) A review of information obtained from four steel producers and 24 consumers on the heat treatment of these steels. Heat treatments, uses, fabrication, protective contings, cleaning, descaling, and available heat-treating furnace equipment are discussed.

Ford heat treat setup combines versatility, output (*Steel*, 1960, **146**, May 2, 72) Equipment is listed.

Useful hints for the practical heat treatment of steels A. Constant and A. Clerc (*Hart. Techn. Mitt.*, 1960, **15**, 32–40) The importance of determining austenite transformation and also continuous cooling curves is stressed. The use of continuous cooling curves for determining hardenability and for hardening of steels is shown. The influence of austenitizing conditions and of segregation on quenching characteristics are discussed. Transformation of residual austenite is dealt with (13 refs).—E.P.

Experimental introduction of a programmed automatic temperature control for heating furnaces G. A. Khasin and V. N. Davidyuk (*Stal'*, 1960, (10), 953) A note from Zlatoust. A modified electronic apparatus is used.

Non-oxidizing heating of steel in a three-zone continuous furnace using oxygen S. E. Bark, A. V. Kozlova, V. M. Kuvshinnikov, M. I. Skvortsova, and V. A. Ustinov (*Kuznechno-Shtamp.*, 1960, (3), 28–33) Existing plants for non-oxidizing heating are classified. A furnace with three zones is suggested in which the new zone would be located between the existing zones for oxidizing and non-oxidizing heating. Heating in the intermediate zone would be non-oxidizing or slightly oxidizing at from 650–700°C to 900–1000°C.

Mass production heat treating line maintains close quality control J. R. Blake (*Ind. Heat.*, 1960, **27**, June, 1168–1178, 1304) Details are given of the new plant of Allen Mgf. Co., making hex-socket cap and set screws etc. Careful layout has been used in the materials handling and storage section, quality control department, and heat-treating plant. In the latter the basement is largely used to supply services and quench tanks. The equipment includes six Holcroft furnaces which harden, quench, wash, and temper in a continuous automatic operation, a rotary carburizing furnace, and batch tempering furnaces.

Recent developments in the field of inductive heat treatment. Thermo-chemical induction treatment (*Härt. Techn. Mitt.*, 1960, **15**, (1), 49–51) The experimental arrangement for thermo-chemical inductive heat-treatment is described briefly.

Machines and equipment for hardening by electro-inductance J. van der Linde (*Metalen*, 1960, **15**, Aug. 31, 272–276) This first instalment of the article describes and illustrates such machines, built by German firms such as the AEG and Schopper & Faeser.—F.B.H.

Recent developments in the field of inductive heat treatment. Inductive nitriding of Armco-iron in aqueous ammonia solution J. Tacikowski (*Härt. Techn. Mitt.*, 1960, **15**, (1), 51–54) The relation between time, temp., thickness, and hardness of the case was investigated as well as the structures obtained. The outer, ε-phase, shows a high nitrogen content up to 1000°C. At 800°C, this phase decreases with increase in nitriding temp. Structures obtained are the same as those for classical nitriding. Maximum hardness of the nitrided case is obtained between 900 and 1000°C. **Inductive carbo-nitriding of Armco-iron in liquid media** H. Matyja (55–56) The relation between time, temp., thickness, hardness, and structure are described. Best results were obtained in a medium consisting of 80% by weight of CH_3OH and 20% saturated aqueous NH_3 solution. The rates of diffusion and structures obtained are the same as with conventional methods.—E.P.

High-frequency hardening of brake pulleys I. F. Glebov (*Metallov. Obra. Met.*, 1959, (2), 54–55) By the technique described, the pulleys are hardened to a depth of 3–4 mm in 4 min. The method consists in rotating the part in a lathe, inside the field of an inductor.

Both ends of steering gear shaft tempered simultaneously by induction heating (*Ind. Heat.*, 1960, **27**, April, 762) A semi-automatic machine, made by Induction Heating Corp., tempers 740 pieces per h. It has a 50 kW, 10000 c/s generator, master control and turntable, cabinet, and semi-automatic tooling. Parts move on a cast Al turntable and are rotated on their own axes. The heating zone has two semi-circular inductors, with compensation for different masses of the work ends. The threaded end is tempered to RC 32 and the slotted end to RC 50.—K.E.J.

Fundamental study on cyaniding and carbo-nitriding. IV. On the carbonitriding diagram F

Yoshikawa (*Nippon Kinzoku* 1959 **23,** July, 414–418) Outer-layer thermal dilatation curves allow the diagram (corresponding with a sectional diagram) to be drawn. It correlates with the microstructure, microhardness, and thermal changes.—K.E.J.

Experiments to clarify the effect of bath nitriding on the fatigue strength of plain steels. I. Soft unkilled steels (0·04 to 0·13%C) and (0·75 to 5 mm cross-section) B. Finnern and O. Schnaber (*Härt. Techn. Mitt.*, 1960, **15,** (1), 20–30) Metallographic, mechanical, and X-ray tests were used in order to find causes for the improved fatigue strength of bath-nitrided plain structural steels. Various hypotheses are discussed and methods of determining the depth of the nitrided layer are compared.

On the question of the structure of the nitrided layer in iron alloyed with titanium T. Konkoly (*Härt. Techn. Mitt.*, 1960, **15,** (1), 88–91) It is shown that if the ratio Ti/C, is below 4, the maximum surface hardness on the nitrided case obtainable is the same as that in absence of Ti but the case is deeper. If the ratio Ti/C is greater than 4, the nitrided depth decreases but the surface hardness increases. The most favourable conditions prevail between 550 and 600°C. Diffusion experiments and X-ray tests were carried out in order to establish the reason for the remarkable properties of the nitrided layer in Ti-bearing iron.

Experimental explanation of the effect of bath nitriding on the endurance strength of plain steels B. Finnern and O. Schaaber (*Härt. Techn. Mitt.*, 1960, **15,** (2), 63–72) The authors discuss results of mechanical, physical, and metallographic tests carried out in order to find an explanation for the high strength of bath-nitrided plain steels. The two main existing theories are considered to be insufficient. The authors suggest that the reason may be found in the effect of hardness phenomena of the under-cooled solid solution which is super-saturated with nitrogen; this results in lattice distortion and blocking, causing increased strength (23 refs).—R.P.

Influence of titanium alloying on the nitridability of iron T. Konkoly (*Härt. Techn. Mitt.*, 13, (2), 102–114) This article describes tests using Ti-alloyed Armco-iron to establish the attainable hardness of the surface layer obtained by nitriding, its thickness, and the progress of hardening, particularly in the transition to the core; to establish the influence of nitriding temp. on the surface layer characteristics and the temp. which gives optimum hardness and nitriding depth; to establish the influence of the coefficient of dissociation of NH_3 on the characteristics of the surface layer and to establish the associated temp. and dissociation coefficient values which give the optimum values for surface hardness and nitriding depth.

The penetration of sulphur in the sulphurizing of steel and cast iron G. V. Karpenko, A. N. Tynnyi, and Yu. I. Babei (*Trudi. Term. Met.*, 1960, **3,** May–June, 18–19; from *Vestnik Maschin.* **37,** (2)) This note describes methods used and results obtained in measuring the depth of the sulphurized layer in ferrous alloys used in a car factory in Minsk. Radioactive sulphur is used. It was found that the sulphur only penetrates 0·015 to 0·016 mm into steel and only 0·034 into iron including the grey surface coating. It is concluded that the increase in sulphur content of the surface is extremely small. This layer possesses antifriction and anti-seizing properties but is still too thin for any subsequent working of the sulphurized pieces.

Mechanism of decarburization and its prevention in annealing baths C. Albrecht (*Härt. Techn. Mitt.*, 1960, **15,** (1), 72–77) Experiments are described to determine the decarburizing or carburizing properties of various annealing baths. The velocity of decarburization is shown to depend on the temp. and alloy constituents. Methods of preventing decarburization are suggested. Cyanide baths may show a carburizing or decarburizing effect, according to their composition. Nitriding in cyanide baths is referred to briefly.—R.P.

Decarburization in salt baths and means for its prevention S. Wilmes (*Härt. Techn. Mitt.*, 1960, **15,** 78–86) Decarburization in salt baths is caused mainly by dissolved and free oxygen. The prevention of decarburization by commercial salt baths was examined, using so-called inert salt baths. Attempts with combustible gases were unsuccessful. Decarburization was prevented under certain conditions, using solid carbon (10 refs).—R.P.

Use of endothermic atmospheres for control of decarburization J. B. Froblom (*Ind. Heat.*, 1960, **27,** June, 1206–1208) The cracking of methane–air mixtures is considered, and curves are given for selecting gas composition (measured by dewpoint) to be in equilibrium with the C content of steel for given temp. Failure of the heat-treatment may arise from lack of continuous record of dewpoint in generator or furnace, catalyst in bad order, steel reaching temp. before dewpoint is reached, excessive CH_4 addition to the furnace, or analysis of furnace dewpoint readings only; without regard to gas composition.

Furnace mock-up useful in explaining new coil annealing process (*Ind. Heat.*, 1960, **27,** April, 788) A short illustrated account is given of a plywood model of a segment of Lee Wilson Engineering Co. Inc.'s new coil annealing system. The full-scale model is used for sales and engineering purposes.—K.E.J.

Versatile barrel furnace line improves production heat-treatment of steel bars J. F. Black (*Ind. Heat.*, 1960, **27,** May, 1002–1008) A compact unit made by Solas Corp. is used to anneal several grades of stainless-steel bars in the hot-rolled or cold-drawn condition, and to normalize other steels. Hexagon, square, and round bars travel at varying speeds, according to size, through the five heating units and an annular quench ring. All operations are automatic. The gas combustion controller holds the 1 : 10 ratio of natural gas and air, and preset pressure, despite variations in demand from all units.—K.E.J.

New furnace boosts bright anneal output General Electric Co. (*Steel*, 1960, **146,** May 9, 148–150) The design and operation of a furnace developed to effect rapid annealing of stainless steel strip are described. The furnace is a vertical tower in which the strip is rapidly heated and cooled, without touching any rolls, as it passes downwards. A protective atmosphere of H_2 or dissociated NH_3 is used; the gas allows Mo heating elements to be used, and is blown on to the strip to effect cooling. Operating temp. is about 2000°F; output can be up to 12000 lb/h of 48 in strip. This bright-annealing process is expected to reduce annealing costs about 50% and extend the range of applications for the material.

Versatility of heating and cooling rates for gear forgings provided by unusual furnace construction L. E. Alban and H. J. Bates (*Ind. Heat.*, 1960, **27,** April, 720–732) An automatic, high-pressure (28 lb/in²), natural gas-fired, two row pusher furnace for annealing, cycle annealing, or normalizing is built by Surface Combustion Corp. It is designed with two main heat-treatment cycles in view, because of variations in steel grade and size and shape of work. It has heating, holding (optional), super-fast cooling, fast cooling, and slow-cooling zones. The throughput is 1200 lb/h (net), of work handled automatically on trays.—K.E.J.

Annealing set-up tames silicon steel (*Steel*, 1960, **146,** May 16, 102) The use of a continuous furnace for annealing grain-orientated silicon steel laminations for transformer cores is described. Each sheet is laid out individually on the furnace conveyor. This practice allows rapid heating and cooling and in many cases treatment in an air atmosphere. The laminations are relatively flat and free of stress and the oxidized surface condition results in an excellent phosphate type insulation coating.

J & L starts new annealing line at Aliquippa works (*Iron Steel Eng.*, 1960, **37,** 152) This continuous annealing line is designed to operate at up to 2000 ft/min, for the production of tinplate. The strip is exposed to closely controlled heating conditions, and an electronic computer is being installed with the ultimate object of regulating temp. and speed variables on the line.

Study of factors influencing ductility of iron–aluminium alloys F. C. Perkins and J. F. Nachman (*AECU–4467*, 1959, Nov., pp.10; from *Nucl. Sci. Abstr.*, 1960, **14,** Feb. 15, 356) Additional heat treatments studies on 13·9 Alfenol tends to confirm earlier observations that reproducibility of ductility values of 8–9% are difficult to obtain. The preparation of Al–Y–Fe and Al–Mo–Y–Fe alloys by arc melting in a non-consumable electrode arc furnace is reported. A resistivity versus temp. curve for the 13·9%Al alloy containing 1%Mo was determined.

Continuous annealing of transformer cores in 182-ft long roller-hearth furnace P. R. LaFalce (*Ind. Heat.*, 1960, **27,** April, 710–716) The cases are made from Hipersil grain-oriented steel strip. Details are given of the electric furnace (several heating and two soaking chambers, slow and fast cooling zones), the automatic control system for temp. and atm control, and the protective atm. which is dried before use. The return-and-storage conveyor brings annealed work back to the loading end and stores it.—K.E.J.

Automatic operation of car-type furnaces expedites heat treatment of castings Waltz Furnace Co. (*Ind. Heat*, 1960, **27,** June, 1232–1234) Two gas-fired furnaces, operating up to 1650°F, with cross-transfers, allow castings to be annealed and preheated, presented for welding, and stress-relieved after welding. Both furnaces may be used for annealing after the welding cycle is completed.—K.E.J.

Heat-resistant alloy rolls for continuous tinplate annealing furnace (*Ind. Heat.*, 1960, **27,** April, 794) The rolls, made by Blaw-Knox Co., are centrifugally cast in 25:12 Cr–Ni alloy. The barrel sections are 18 in in dia. and 55 in wide. The roll face is ground to a min. finish of 32 μ in. The furnace operates at 1600–1675°F.

Wire treatment in salt baths R. Kuhn (*Wire World Int.*, 1960, **2,** April, 65–67) A description is given of the method and advantages of scale-free annealing of austenitic wire in salt baths and descaling in salt baths. It is concluded that the cost of salt bath methods is justified by the elimination or reduction of metal losses. The system is therefore particularly suitable for alloyed wires. Treatment defects such as hydrogen embrittlement and pitting are prevented. There is no effluent disposal problem and the very short treatment times make the entire process suitable for automation.

A way of increasing the output of patenting furnaces S. S. Kazekavich, E. S. Borisovskii, R. S. Kuleshov, and A. A. Golovanov (*Stal'*, 1960, (10), 957–959) The new method of lining muffle sections in patenting furnaces consist of replacing the usual lining material; chamotte, carborundum, etc., with siphon bricks arranged checker fashion. This improves heating by increasing the surface in contact with the hot gases, thus speeding up the operation and raising output. Furthermore the savings for lining the muffle sections are considerable (the reduction in costs is to an eighth or a ninth). A number of patenting furnaces have been reconstructed in conformity with the scheme here explained.

A combined heat treatment plant incorporating a quench tank (*Wire Ind.*, 1960, **27,** March, 271) The Ipsen combined heat treatment plant is described. It will effect a variety of processes at up to 1100°C.—D.L.C.P.

Experiments on improving the quenching properties of 12 Ch steel Kao Feng-yi and Ko Chiun (*Iron & Steel (China)*, 1958, (9), 63–69; from *Sci. Abs. China, Techn. Sci.*, 1959, (1), 48) A series of tests is reported. A smelting procedure is proposed for steels of various quenchabilities, and inspection instructions for them are given. The relationship of composition and other factors to quenching properties are discussed.

Press quenching under exact control (*Metallov. Prod.*, 1960, **104,** June, 988–989) Heat-treatment of crown wheels and other scars on 12 Gleason machines at Ford's Dagenham works is described, showing automatic electronic control, and using heat radiated by the component to initiate and control the full operating cycle.—S.H.-S.

On the deterioration of quenching oil. V. On the deterioration of quenching oils by heat decomposition M. Tagaya, I. Tamura, and M. Tanaka (*Tetsu to oagane*, 1960, **46,** April, 483–487) The testing apparatus utilizes repeated

quenching from 900°C of a Ni–Cr coil. Data are given for mineral and fatty oils, and mineral oil with 10% polymerized hydrocarbon added. Deterioration was markedly less than by oxidation or polymerization, but the flash pt was significantly lowered.—K.E.J.

Reducing the deformation of tools during hardening N. N. Lipchin (*Metallov. Obra. Met.*, 1959, (2), 56–59) Deformation of steels V8–V12 was reduced by quenching in an aq. soln. of 35–45%NaOH at 20°C. Tools of steel KhVG should be hardened and heated isothermally in the martensite range at 160°C in alkalis or KNO_3 or at 110°C in a 75% aq. soln. of NaOH. High-speed tools susceptible to warping should be hardened and heated isothermally in the martensite transformation range at 170–180°C in KNO_3 or alkalis.

Adjusting and operating at the Dzezhinsk works a new method of sorbitizing rails P. T. Besedin, G. G. Oreshkin, A. A. Sorokin, A. M. Karpunin, P. M. Chepelev, A. F. Vasil'ev, and A. D. Kutsenko (*Stal'*, 1960, (10), 946–953) This new method of heat-treatment of rails, especially the sorbitization of the rail heads along their full length as worked out at the Dzezhinsk works, improves appreciably their mechanical properties. In contrast to the older practice which carried out this operation by continuous sorbitization of sections in a stationary rail held fast between two clamps, the present method sorbitizes with discontinuous hardening in sections, through which the rails are continuously and steadily moving. A special furnace and a sorbitizing unit, in commission now for several years, are described. It was also established that rail steel should be deoxidized with larger quantities of Al than were currently used but that this should be added in the form of ferroalloy or of a Mn–Al alloy in order to increase the proportion of metallic Al in solid solution.

The heat treatment of dies. II M. Tossi (*Tratt. Term. Met.*, 1960, **3,** July, Aug., 15–22) Dies and punches for blanking and drawing are dealt with. The form of the die tempering in a chamber furnace, the quenching bath, and burning off are described.

FORGING, STAMPING, DRAWING AND PRESSING

Largest forge shop has 87 furnaces for forging and heat treating operations (*Ind. Heat.*, 1960, **27,** June, 1182–1188) A general description is given of operations at Kropp Forge Co., the world's largest producer of forgings. Steel bars, shafts, and forgings are produced. Hammers range from 1000 to 50000 lb capacity. There are 68 forging furnaces and 19 gas-fired heat-treatment furnaces of various kinds.—K.E.J.

Waterbury Farrel gets set for big gains in cold forming (*Steel*, 1960, **146,** May 9, 144–145) It is explained that cold forming can be more economical than machining for the following reasons: parts are stronger and harder than the raw material; waste is reduced; raw material is cheaper; rejects are low.—D.L.C.P.

The manufacture of bush-type forgings P. Wasiunyk (*Obraboka Plast.*, 1959, **1,** (3), 119–128) The author gives the theoretical as well as the practical aspects of the problem. Formulae are given and coefficients are evaluated. As far as drop forging is concerned the author points out that the use of upset forging machines gives considerable material saving and increases the production rate several times.

Semi-automatic manipulator for closed-die forging hammers M. A. Albert (*Kuznechno-Shtampovochnoe Proizvodstvo*, 1959, **1,** (7), 38–40) A plan and description of the manipulator driven by 1·2 kW electric motor through reducing gear are given.

Precision big-press forgings cut down chip machining A. E. Favre (*Iron Age*, 1960, **185,** May 19, 158–159) The uses of 35000 and 50000 t hydraulic presses are described. In an example, a 1400 lb hand-forging was replaced by a 290 lb big-press precision forging with considerable detail pressed in.—D.L.C.P.

Rejects caused by compression during the pressing of forgings with symmetrical axes and methods of preventing such rejects O. A. Ganago and A. E. Dammer (*Kuznechno-Shtamp.*, 1960, (1), 7–10) Experiments have established the mechanism of the formation of compression in the annular cavities of dies. Compression begins to take place as piercing develops, i.e. from the moment the metal comes into contact with the side walls of the die. It has been found that the dimensions of the initial blank are a very important factor.

Accurate forging without cutting-off in countries abroad I. F. Golovnev (*Kuznechno-Shtamp.*, 1960, (4), 23–25) Accurate forging without the need for the cutting-off of excess metal reduces discard and net cost and makes it possible to make machine parts from low-ductility alloys. Experience with toothed gears in the Federal German Republic, with turbine blades and other forgings in the USA, and with the cored forging process in the UK is described.

The effect of hot-working conditions on the properties of large manufactured parts M. P. Braun, B. B. Vinokur, E. I. Mirovskii, A. L. Geller, and L. G. Mar'yushkin (*Kuznechno-Shtamp.*, 1960, (4), 8–11) When forging ingots made from certain types of steels an increase in heating temp. of 30–40°C compared with current practice does not adversely affect ductility during deformation and in certain cases does not lower mechanical properties (12 refs).

The choice of the temperature range for the forging and stamping of carbon steels B. F. Trakhtenberg (*Kuznechno-Shtamp.*, 1960, (5), 21–26) The upper and lower limits of the temp. range for forging carbon steels are discussed. Hypoeutectoid and hypereutectoid steels are considered separately (10 refs).

Resistance of the metal to deformation during forging in crankshaft presses V. S. Goffenshefer (*Kuznechno-Shtamp.*, 1960, (6), 18–22) A method is proposed for calculating the basic factors affecting the resistance to deformation of metal during hot pressing with the formation of flash in crankshaft presses (open dies) (15 refs).

A French forging press fed by direct oil pumps (*Usine Nouv.*, 1960, **16,** Oct. 20, 31) This note briefly describes the design, operation, and advantages of a 1000 t forging press fed by direct oil pumps, the first of its kind to be constructed in France, for installation at the Acieries de Champagnole for high alloy forgings.

Adjusting the methods ensuring the required mechanical properties of ferrite high-chromium steels of type Kh25 G. A. Khasin and V. N. Davidyuk (*Stal'*, 1960, (10), 953) A note from Zlatoust. Forging from not above 1050° to 700–800° gave the necessary ductilities. Corrective heat-treatments are indicated.

Standard presses linked in automatic line D. Scott (*Metalw. Prod.*, 1960, **104,** April, 706–707) A link-line featured among East German presses at the recent Leipzig Fair is described. It is formed by three standard 10-t hydraulic machines with individual transfer mechanisms housed in cabinets in front of each machine and shuttling carriers conveying work between adjacent unload and load arms.—S.H.-S.

Cold heading process trims part costs (*Steel*, 1960, **147,** July 18, 99) Substantial cost savings were realized by switching from screw machines to cold headers at General Motors Saginaw Steering Gear Div.—S.H.-S.

The bulletin of the Central Laboratory for plastic deformation W. Grzeskowiak and A. Turno (*Obrobka Plast.*, 1959, **1,** (3), 151–160) The article deals with matters of terminology used in Polish papers.

Precision shaving, blanking and piercing G. Oehler (*Obrobka Plast.*, 1959, **1,** (3), 57–82) To obtain higher quality stampings, special tools can be fitted to normal presses and other machine tools. This is described in some detail. A microprofilometer can be used for quality control and it is found that good quality and maintenance of the cutting tool itself is of prime importance. No means of drawing satisfactory conclusions on economic grounds can be suggested.

The measurement of load in mechanical power presses Z. Wisniewski (*Obrobka Plast.*, 1959, **1,** (3), 83–100) Two methods of measuring dynamic loads and frame rigidity are dealt with. First, the use of hydraulic loading with resistance strain gauges. Second, an original method by means of the deformation of a lead ring. It is claimed that the deflection of the frame of a gap-type press can be obtained directly from the inclination of the initially parallel surfaces of the lead ring.

Sheet metal forming tools made from plastics produced in Poland I. Gruin (*Obrobka Plast.*, 1959, **1,** (3), 129–150) It was found that the most important plastics for this purpose were epoxy-resins, though Polish products were not of the required quality. However, modified Epidian 3 resin produced in Poland was found satisfactory on tests on Wheelon presses, eccentric and screw presses and hammer forgings, particularly for short runs.

Combined dies with a clamping device R. N. Zuev (*Kuznechno-Shtamp.*, 1960, (2), 40–42) The principle of operation of these dies is explained and illustrations are given showing how they are used for various purposes: cutting to shape of machine parts, bending of flanges through 90°, and the forming and punching of holes in flanges and tubes. The dies are arranged vertically and operate consecutively, with first one and then the other die clamped firmly into position while the other die moves.

Improving the pressing of motor-car parts and the forgeability of sheet steel V. M. Chirkin (*Kuznechno-Shtamp.*, 1960, (3), 8–10) In the pressing of motor-car parts, such as roofs and wings, the reject figure is high. The author examines this problem from the viewpoint of the steel used and considers such questions as mechanical properties rather than stamping techniques.

A mechanized line for the pressing of external door panels of the GAZ-51 motor car N. P. Yashnov, V. V. Kolobov, and G. V. Grekov (*Kuznechno-Shtamp.*, 1960, (3), 24–27) The Gor'kii motor-car factory has recently introduced a mechanized line for making external door panels for the GAZ-51 motor-car. A diagram of the line is shown, the equipment in the line is named, and operations are explained. This new line has released 11 workers, increased labour output by 46%, and the capital outlay will be recovered in three months.

Determination of the force of the press and the weight of the tups of the hammers required for hot stamping O. A. Ganago, R. A. Vaisburd, and I. Ya. Tarnovskii (*Kuznechno-Shtamp.*, 1960, (4), 1–7) It is pointed out that forging with open presses takes place in two stages: (a) filling the cavities with metal, and (b) forcing excess metal into relatively narrow areas. The forces required are different in each stage. Data are given on the effect of the shape of the forging, on industrial tests of formulae for calculating the forces during forging, and on determining the weight of the tups of forging hammers.

Technological lubricants for stamping thin steel sheet A. V. Korolev and I. V. Podluzhnaya (*Kuznechno-Shtamp.*, 1960, (5), 14–15) Investigations carried out into technical lubricants have shown that during the cold forging of steel sheet, stable lubricants should be used with an additive such as talc. In choosing a lubricant its properties and its effect on the drawing process should be determined first of all under laboratory conditions.

Development of swaged stainless steel fuel rods containing UO_2 J. T. Lamartine and W. C. Thurber (*CF*–59–10–8, 1959, Oct. 12, pp.46; from *Nucl. Sci. Abs.*, 1960, **14,** Feb. 15, 354) A programme was initiated to evaluate rotary swaging as a technique for fabricating stainless steel fuel rods containing UO_2. Emphasis was placed on a parametric study to determine the effects of type of UO_2, total reduction, swaging temp., and particle size on the swaged density of UO_2 in 304 stainless steel tubing; findings are reported.

New plant for heavy fabrication (*Weld. Met. Fabr.*, 1960, **28,** April, 140–144) This article describes a £400000 development scheme recently completed at Hugh Smith and Co. (Possil) Ltd. The new production facilities are described, including a new production bay, a ship's frame bending machine, plate straightening rolls, plate bending rolls, a heavy duty direct acting hydraulic press, a gap type hydraulic press, and a plate edge planer.

Simca mechanises body assembly D. Scott (*Metalw. Prodn.*, 1960, **104,** May 11, 851–855) An illustrated account of extensions at the Poissy car factory.

Venturi nozzles produced by explosive forming plus spin forging Marquardt Corp. (*Metalw. Prodn.*, 1960, **104**, Aug. 31, 63–65) Large savings have resulted from the shaping of stainless steel nozzles in this way instead of welding and machining.

High energy rate metal forming G. N. Rardin and A. F. Watts (*Interim Engineering Report No.2, LR*–13350, pp.53; from *Nucl. Sci. Abs.*, 1959, **13**, Aug. 15, 1815–1816) Design and manufacture of equipment, material preparation, and instrumentation in tests on the explosive forming of sheet metal parts are described.

High energy rate forming G. N. Rardin and A. F. Watts (*LR*–13435, pp.43, from *Nucl. Sci. Abs.*, 1959, **13**, Aug. 15, 1816) Evaluation of the results of using high explosives of different weights and distances for forming hemispherical cups.

Hydrospark forming offers control, high accuracy (*Steel*, 1960, **147**, July 11, 92–94) A high intensity electrical spark discharged in water, and exerting hydraulic pressure to deform metals for aircraft and missile parts is briefly described and its advantages are indicated.—S.H.-S.

The production of seamless tubular arcs by hot drawing V. Popelář (*Hutn. Listy*, 1960, **15**, (8), 619–625) The theoretical and practical experience gained by the author in the Vítkovice Steelworks in connexion with the production of such tubes from 1932–60 is discussed.—P.F.

Fundamentals of sheet metal forming based on extension Z. Marciniak (*Obrobka Plast.*, 1959, **1**, (3), 7–26) The author examines the stress and strain distribution in bulge forming or hole expanding of sheet blanks with a large peripheral flange. First, the action of hydraulic fluid, then that of a rigid punch are examined. Equations, allowing the determination of wall thickness changes are formulated and loss of stability and effects of friction and modes of failure are considered. In conclusion several criteria for the selection of a satisfactory shaping method to give a selected shape are considered.

Development of the process of the 'warm' drawing of coiled steel G. A. Khasin and V. N. Davidyuk (*Stal'*, 1960, (10), 934) A note from Zlatoust. Laboratory trials are quoted showing the ductility maxima for the high-alloy steels used. Electric heating was used in front of the draw-plates and drawing was carried out at 46 and 10 m/min.

Study of the causes of brittleness in Kh18 steel during cold drawing G. A. Khasin and V. N. Davidyuk (*Stal*, 1960, (10), 935) A note from Zlatoust. Some sheets ruptured in drawing, especially when near the upper limits of C and Cr. X-Ray analysis of precipitates showed the presence of a trigonal Cr_7C_3, as well as the normal $Cr_{23}C_6$, of much greater hardness. Annealing at 740°C with quenching after each pass is recommended.

Fabrication of 17-7 PH and PH15-7 Mo stainless steel by bend rolling, deep drawing and spinning C. T. Olofson (*DMIC-Memo*–18, 1959, May, pp.4; from *Nucl. Sci. Abs.*, 1959, **13**, Aug. 15, 1815) Fabrication procedures are given; in general, these follow the lines of the procedure for 301 stainless steel, with certain modifications in some cases.

Determination of the working time in steel wire drawing G. Ranzi (*Ing. Mecc.*, 1960, **9**, Aug., 17–21) A calculation is made of the dry drawing time of steel wire with an initial resistance Ro which is passed several times through the drawing die. The time for any drawing pass can be calculated by dividing the length of the drawn wire by the drawing speed. As the length is, however, difficult to measure whereas the weight of the wire skein and the cross-section of the drawn wire are known, the time can be expressed as a function of these two variables.

Wire mill production, planning and control F. Wilcox (*Wire World Int.*, 1960, **2**, April, 68–71; *Wire Ind.*, 1960, **27**, April, 365–368) A description is given of a Rylands Brothers wire drawing mill including the stockyard and sidings. Production planning from receipt of order to delivery including quality control and die control are dealt with.

The effects of contamination by chromium, nickel and copper in the steel for patented rope and steel wire on their mechanical properties J. Goczal (*Prace Inst. Hutn.*, 1960, **12**, (3), 145–157) The following conclusions are drawn from the investigation: (1) Chemical analysis should be the basis for the evaluation of the suitability of the material for high-quality steel; (2) An increase of Cr content up to 0·15% and Ni up to 0·20% is acceptable, though Cu should be kept down to 0·20%; (3) In order to maintain constant quality the lead bath temp. should be related to the carbon content in all cases.

The role of lubricants in wire drawing G. Dévényi (*Koh. Lapok*, 1960, **93**, May, 212–216; June, 279–282) The author reviews and summarizes the recent investigations on the role of various lubricants and lubricant-bearing materials in wire drawing. The coefficient of friction is a function of the mean surface-pressure, and increases proportionally with this. Among the lubricant bearing materials, lime is advantageous, only the alkalis are better. The friction coefficient of metal stearates is lower than that of soaps. The use of lubricants consisting of graphite and MoS_2 is only advisable at high surface pressure.—P.K.

Hardness distribution in drawn steel wires. III. Effect of rapid heating during heat treatment and special drawing methods on the hardness distribution. IV. Effect of special working and tempering conditions on hardness distribution T. Nishioka and Y. Yasukuni (*Nippon Kinzoku.* 1959, **23**, Sept., 511–515; 515–518) [In Japanese, with German summaries].

Steel jacket protects beryllium during extrusion process R. C. Harris (*Iron Age*, 1960, **186**, July 7, 84–85) Be tends to seize or gall when extruded, and a new process, using seamless steel jackets, is claimed to prevent both seizing and galling and also to preclude oxidation and to serve as lubricants. Good finish and high reduction ratios are shown.—S.H.-S.

ROLLING MILL PRACTICE

Principles of design of planetary rolling mills K. Stýblo (*Hutn. Listy*, 1960, **15**, (8), 609–615) [In Czech].—P.F.

The control model as an important aid in the solution of control technological problems K. Anke and H. G. Müller (*Stahl Eisen*, 1960, **80**, Oct. 13, 1382–1389) Mathematical. The application of the analogue computer for the solution of problems in the iron and steel industry, particularly in the rolling mill section, is considered.—T.G.

Description of the Sendzimir mill Y. Ueda (*Nisshin Seiko Giho*, 1959, Dec., 48–57) A detailed description with ample illustrations and diagrams is given, of the layout and operation of the mill.

Forge blank rolling T. Rut (*Obrobka Plast.*, 1959, **1**, (3), 27–55) The technological fundamentals of the forge rolling processes are discussed. Dimensional changes caused by various roll-die-grooves (flat, rhomb, oval, square, and box) are examined. In conclusion, roll selection and design and economic aspects are discussed.

A vacuum rolling mill V. M. Amonenko, A. S. Tron', V. V. Mukhin, and V. A. Tarasov (*Stal'*, 1960, (10), 920–922) In the rolling of heat-resisting alloys, especially of W, Mo, U, Zr, Nb, and Ta, cracks develop which are not sealed up on further rolling on account of scale formation and also brittleness is produced by oxidation. Plans of a mill using vacuum or an inert atmosphere are shown. Details of the mill are given and experimental rolling of Mo and other alloys down to 0·3 mm sheet has been carried out.

Maximum reductions in cold strip rolling B. Avitzur (*Chartered Mech. Eng.*, 1960, **7**, Sept., 356) An equation is advanced for maximum reductions with no forward slip.

Considerations on the design of the corrugating machine for galvanized sheets T. Omoto (*Nisshin Seiko Giho*, 1959, Dec., 44–47) Normally a decision regarding the form of the rolls for a corrugating machine is taken after using testing rolls or as a result of the machine designers' experience. The writer has theoretically calculated the form of the rolls from the behaviour of galvanized sheet under corrugation and by reference to the conventional roll. Successful results have been obtained using rolls designed by this method.

The selection and use of a water soluble rolling oil P. W. Coffman (*Iron Steel Eng.*, 1960, **37**, June, 69–77) Experience of Acme Steel Co., Chicago in the selection and use of rolling oil is described in detail. Acme have also used the oil successfully for bearing lubrication on the same mill.

The determination of force and performance in plastic deformation of metals E. Kiss (*Koh. Lapok*, 1960, **93**, May, 206–211) The author describes the measurement of force and performance carried out in the Mannesmann tube mill at Csepel and in the three-high plate-mill at Pestszentlorine.—P.K.

Observations on the deformation of twin metals during hot-rolling R. Fishgold and I. Dragan (*Rev. Roumaine Met.*, 1960, **5**, (1), 59–71) [In German] The principal parameter which affects deformation is the ratio of the strength of the two component layers $k = H_1/H_2$. The stronger layer tends to take over the greater part of the deformation. The path of the $\Delta b = f(k)$ and of $\Delta h = f(k)$ curves for values of $k > 1$ points to a relatively constant relation between the partial reductions (h) and increased in width (b). The increase in the total value of the reduction does not alter qualitatively the relation between these curves. A good cladding is obtained by a proper selection of the optimum value for the ratio $\frac{H_1/H_2}{h_1/h_2}$.

Investigation of metal flow and the field of force in the deformation zone using cinephotography and rolls of special design N. M. Lapotyshkin (*Stal'*, 1960, (10), 935) A note from TsNIIChM. It is mentioned that such studies have been made.

Moment of inertia, and safety of rolling-mill motors W. Köller (*Stahl Eisen*, 1960, **80**, Oct. 13, 1426–1428) The authors report and discuss a method of calculation of the moment of inertia and the safety of large rolling-mill motors which was suggested by Pirk and Putz in *Konstruction*, 1959, **11**, 486.—T.G.

Calculation of the peak or shock impulse of electric motors with the aid of analogue computers L. Hannakam (*Stahl Eisen*, 1960, **80**, Oct. 13, 1389–1397) Mathematical.—T.G.

New designs for rigid stands in rolling mills I. F. Prikhod'ko (*Stal'*, 1960, (9), 819–824) Prestressing of the bolts holding the stands and other alterations improving rigidity, increased accuracy of dimensions, and reduced the number of sheets outside tolerances.

Rolling with increased reductions A. I. Murzov (*Stal'*, 1960, (9), 824–826) An arrangement for tightening down the rolls during rolling is claimed to increase output by reducing the number of passes.

Rolling with 'super-reductions' V. P. Kozhevnikov and M. M. Shternov (*Stal'*, 1960, (9), 827–828) It is claimed that the use of greater reductions and fewer passes does not increase output except under special circumstances with blooming mills.

Bethlehem offers vacuum-cast rolls (*Iron Age*, 1960, **186**, July 21, 99) A brief report.

Raising the wear resistance of the rolls in the 280 mill roughing stands G. A. Khasin and V. N. Davidyuk (*Stal'*, 1960, (10), 935). A note from Zlatoust. Use of Ul0KhNM and 45KhNMFA steels for rolls with suitable heat treatments is advantageous.

Technology of the manufacture of high carbon alloy steel rolls H. Uhlitzsch and G. Radomski (*Neue Hütte*, 1960, **5**, Aug., 447–451) The use of these rolls in various mills is reviewed, and formulas and diagrams are developed for the calculation of a mould and hot top design for their manufacture, and directions for the holding time before stripping, and subsequent stress-relieving heat treatment.

New drive and control system powers steel rolling mill (*Iron Age*, 1960, **186**, July 21, 142–143) The automatic control system of US Steel's new South Works structural mill, its efficiency and first year results are briefly outlined.—S.H.-S.

Modern drives, controls automatic structural mill United States Steel Corp. (*Steel*, 1960, **147**,

July 11, 100) Drive and control systems integrating mechanical and electrical equipment and turning out a 250 ft structural steel beam every 19 sec when operating at full speed is described.

Pipe rolling mills T. Migda (*Prz. Techn.*, 1960, **81**, (18), 17–19) The rolling and drawing of tubes is the subject of this article. The problems of manufacturing HP boiler tubes from ferritic-pearlitic Mo steels have been solved. Problems resulting from Polish Standards have also been dealt with. In the field of high temp. and acid-resistant tubes, considerable progress has been made. However, difficulties have been encountered in rolling austenitic steel tubes on account of the formation of flakes and cracking. In order to save high-alloy steels, work is in progress to introduce vinyl laminated pipes.

Selecting a method of production for large diameter thin-rolled tubes A. B. Vernik (*Stal'*, 1960, (9), 828–830) The high cost of sheet steel is claimed to make Pilger mills with elongators and expanders more economical than the electric tube welding mills.

Investigation of the parameters of the secondary piercing of extra thin walled shells P. A. Trubchenko, I. Yu. Korobochkin, N. S. Kirvalidze, and A. A. Shvedchenko (*Stal'*, 1960, (10), 922–928) Factors affecting power used and reduction achieved are discussed. Effects of exit roll taper are especially examined. The data found are used to arrive at the best dimensions and conditions for the process.

On the mechanism of metal rupture in the course of cross-rolling P. K. Teterin and Yu. F. Luzin (*Stal'*, 1960, (10), 930–932) Theories are briefly reviewed and studies on the cross-rolling of composite billets are reported. Three discs, the middle one 8 mm thick and the others 25 mm and welded only at the periphery were used to eliminate axial effects on the middle disc. Rupture was caused by transverse tensile stresses and intensive plastic deformation at the centre precedes rupture.

Study of a new process of oblique rolling N. M. Lapotyshkin (*Stal'*, 1960, (10), 935) A note from TsNIIChM. Advantages of the three-roll helical mill are set out.

A study of the deformation and stresses in oblique rolling: determining optimum piercing conditions for deformation-resisting steels N. M. Lapotyshkin (*Stal'*, 1960, (10), 935) A note from TsNIIChM. The kind of investigations made are indicated.

Improving the productive efficiency of electric resistance weld tube mills E. J. Swinn (*J. Inst. Prod. Eng.*, 1960, **39**, June, 357–364) The author describes ways in which a firm which has recently installed such a mill can improve efficiency by ensuring that the correct process conditions obtain by work study and analysis. Solutions are suggested to certain technical problems which occur, many of which are due to the initial lack of experience of the operators.

A method of determining the effect of altering wall thicknesses and the service life of hot-rolled tubes N. I. Leibovich (*Stal'*, 1960, (9), 831–832) Calculations are presented to assess savings by reducing wall thickness. The effects of an increase or decrease of service life on costs to the user are included.

The cutting of plate and strip steel with rotary shears H. J. Crasemann (*Arch. Eisenh.*, 1960, **31**, Aug., 459–470) The field of application of different types of rotary shear, distribution of power in the cutting zone, and the cutting process are discussed, and factors influencing the quality of the cut are examined. A new method of calculation of power and output requirements is described.

Bar cropping machine gives square, clean ends Soleco Co. (*Metalw. Prodn.*, 1960, **104**, July 6, 89–91) Reactron machines are described and illustrated. The largest cuts bars up to 2¾ in dia.

Giant saw cuts rolled plate Shultz Steel Co. (*Iron Age*, 1960, **186**, July 28, 83) The use of the new Pan-Arm saw, to cut the cross-rolled plate produced at the suggestion of the US Aircraft Research and Testing Committee, its equipment and operation, are very briefly discussed.—S.H.-S.

Small gauge reelers V. I. Mishchenko (*Stal'*, 1960, (10), 933–934) The installation of Garret and Edenborn type reelers for rolled wire and faults found in them are described. Design is discussed. Guiding of the wire into the reeler is improved.

Precision cutting by lateral extrusion of the metal against the cutting punch G. Oehler (*Techn. Mod.*, 1960, **42**, July, 352–355) In many cases double cutting of steel strip is necessary, the first cut by the normal mill tool and a second precision cut as part of the finishing process. This article describes two processes which have been developed recently which carry out a precision cut at the strip cutting stage. One of these is called the 'countercut' process and the second, 'transverse extrusion'.

Television equipment on the rolling mill E. S. Belilovskii (*Stal'*, 1960, (9), 834–835) A wire rod mill in which the billets are delivered to the side away from the operator has been fitted with closed circuit television.

MACHINERY AND SERVICES FOR IRON AND STEELWORKS

New Margam power plant. Britain's first Benson Boiler (*Metallurgia*, 1960, **62**, July, 3–7) Fired by blast-furnace gas and capable of generating 240 000 lb of steam per h at a pressure of 3 300 lb/in² and a temp. of 1 060°F with reheat to 836°F, the Benson boiler will power the highest pressure turbine in Britain. A description with cross-section diagram is given.

Recent improvements in mechanical weighing machines for the iron and steel industry H. Fricke (*Stahl Eisen*, 1960, **80**, Oct. 13, 1398–1403) A number of examples of modern weighing machines, mainly for internal use in iron and steelworks, are described and future trends are indicated.—T.G.

Conveyor belt type weighing machines for measuring predetermined quantities in the iron smelting industry A. von Petery (*Stahl Eisen*, 1960, **80**, Oct. 13, 1404–1410) Design, construction, features, application of the conventional 'adding' and the novel electronic 'integrating' conveyor-belt type weighing machines are described and their usefulness discussed. A number of applications are described.—T.G.

Electric weighing machines in the iron smelting industry J. Oemigk (*Stahl Eisen*, 1960, **80**, Oct. 13, 1411–1414) Principles and uses of electric weighing machines in the iron industry are considered. Their main field of usefulness lies in applications where the results are evaluated at a centre remote from the place of weighing or where they are part of an electric control system. In this connexion they have another advantage in so far as the results may be presented in digital form for direct feeding into computers.—T.G.

Systematics in the maintenance of electric plant in industry K. H. Lopitzsch (*Stahl Eisen*, 1960, **80**, Oct. 13, 1414–1417) This is a theoretical treatise on the systematics of the maintenance of electric plant; the author discriminates between lower and higher degrees of maintenance, he discusses the main causes of defects and the probability of their occurrence; from this he deduces a schedule for maintenance. Training of personnel is also included.

Charging for the work done, and distribution of the costs to all departments of a works' own railway W. H. Mieth (*Stahl Eisen*, 1960, **80**, Oct. 13, 1428–1431) The internal accounting system for a works' own railway in an iron and steelworks as suggested by M. Forterre in a lecture to the International Transport Meeting at Liège in 1958 is reported and discussed.

Safe control of a mixed gas distribution system without the use of a holder B. D. Barns (*Iron Steel Eng.*, 1960, **37**, June, 122–126) Using the modifications described, the Ford Rouge plant's mixed gas system was operated successfully for 36 days without a gasholder.

Electronic maintenance training at Allegheny Ludlum Steel Corp. J. C. Haube (*Iron Steel Eng.*, 1960, **37**, June, 78–85) The organization of an electronic maintenance group in relation to the automatic control programme in this Company's works is described.

WELDING AND FLAME CUTTING

Welding Conference at Metz. I. Chemical composition and weldability A. Leroy (*Soud. Techn. Connexes*, 1960, **14**, July–Aug., 269–726) The weldability of steels is considered in relation to the welding process used and to the properties aimed at. Weldability is shown to depend on the type and distribution of the phases present and, to a limited extent, on the chemical composition. The influence of various constituents is discussed. **II. Remarks on weldability tests** H. Granjon and A. Audigé (276–282) The development of studies on weldability is reviewed. Main testing techniques are discussed, based on a classification corresponding to the fundamental aspects of weldability. The role of weldability tests in research, control, and acceptance is outlined (21 refs).—R.F.

Welding and allied processes in the maintenance departments of the French National Railway Company R. Biais and P. Gauthier (*Soudage Techn. Connexes*, 1960, **14**, July–Aug., 311–320) Recent developments in welding and allied processes in railway maintenance work are discussed from technical, economic, and human angles. Typical examples are given of applications of arc, oxy-acetylene, resistance, and thermit welding, cutting, and metal spraying. Conditions are laid down regarding procedure, inspection, and welder qualifications.—R.F.

Welding in the U.S.S.R. Report by the French Mission on Welding in the Soviet Union, Nov. 1959 M. H. Granjon (*Soud. Techn. Connexes*, 1960, **14**, July–Aug., 249–256) Report by a Mission on the techniques of welding and work carried out in this field at Moscow, Leningrad, and Kiev.—R.F.

Welding of stainless steels. A review H. Suzuki (*Tetsu to Hagane*, 1960, **46**, April, 498–520; May, 578–588) (38 refs).—K.E.J.

Electron unit solves problem of welding refractory metals A. Adelhardt and R. H. Witt (*Iron Age*, 1960, **185**, April 28, 108–110) Electron beam welding of Mo, W, and stainless steel is described.

Spot welding soft steel with low carbon content G. A. Phipps (*Cien. Tecn. Solda.*, 1960, **10**, May–June, {5(514)}, 1–6) A revised form of this section of the BWRA Code of Practice, introducing some amendments and additions based upon observations made by Commission III of the International Welding Institute and on important tests made by BWRA. Further revisions are forecast.—S.H.-S.

On welding of steels with fundamentally different structures V. Pilous (*Zváranie*, 1960, **9**, (8), 237–242; (9), 260–263) In the construction of gas and steam turbines the problem of welding ferritic and austenitic steels together often arises. The problem is discussed with special reference to methods used, and researches carried out in Czechoslovakia in recent years.—P.F.

Welding of ferritic to austenitic steels: Review of progress J. Class (**Verein, der Grosskesselbesitzer, Mitt.*, 1959, June, 181–207) An extensive review of methods and tests is given and a table of factors deleterious to welds and methods of minimizing their effects is shown. The best solutions involve welded-in transition pieces, some with Ni intermediate layers, or high-Ni filler metal for direct butt welding. These are somewhat costly, and the need for inexpensive transition pieces is pointed out (43 refs).

Iron–aluminium alloy systems. Part 14: welding of iron–aluminium alloys R. Brooks and A. Volio (*WADC–TR–57–298* (Pt14); *AD* 213473, 1959, April, pp.29; from *Nucl. Sci. Abs.*, 1959, **13**, Aug. 15, 1818–1819) Investigations were continued on the development of fusion welding procedures for Fe–Al alloys, and fabricated parts from Fe–Al alloys were completed and submitted for service. A description of the procedures and of the examination of a component damaged during endurance testing is given.

Welding copper pipe to stainless steel flanges in a laboratory workshop J. Leece (*J. Sci. Inst.*, 1960, **37**, June, 219–220) Methods of brazing stainless steel to copper in a high vacuum by means of a radiofrequency induction heater are usually conducted within a glass vessel to allow the operator to control progress. However, if the components are large or unwieldy the size of the vessel may become prohibitively large and the presence of jigs may lead to poor

rf coupling. To overcome this a satisfactory method has been developed using a conventional argon arc non-consumable electrode welding set in normal workshop conditions.

NPR, Tube to nozzle connection and Zircaloy-2 to stainless steel tube connection W. R. Smith and H. H. Klepfer (*GEAP*–3089, 1958, Nov., pp.30; from *Nucl. Sci. Abs.*, 1959, **13,** Aug. 15, 1815) Fusion bonding was used for joining Zircaloy-2 tubing to stainless steel tubing, and W-inert gas welding to join a flange to a pressure tube.

Truck frame fabrication speeded by 200 ipm welds A. O. Smith Corp. (*Steel*, 1960, **147,** July 18, 88) Two welding machines fabricating truck frames in two wheelbases by which two men loading each welder can turn out about 85 assemblies/h, are described.—S.H.-S.

The Arcair process G. Doneux (*Schweisstechn.*, 1960, **14,** (4), 37–42) The Arcair method is shown to depend on a melting effect of the electric arc, the molten material being removed by a compressed air blast. The construction of the tool is described and numerous uses for cutting and drilling all kinds of ferrous and non-ferrous materials are given.—B.P.

Hydrogen in welding P. Bastien (*Riv. Saldatura*, 1960, **13,** July–Aug., 174–187) The effects are examined of H_2 with special reference to flaking in steel ingots, castings, and in weld metal. Theories are then advanced to explain the causes of the H_2 inclusion and the resulting brittleness with regard to elastic and plastic deformation. Conclusions are drawn with special application to welding.

Welding of high strength steels for aircraft and missile applications H. W. Mishler, R. E. Monroe, and P. J. Rieppel (*DMIC*–118; *PB*–151074, 1959, Oct. 12, pp.94; from *Nucl. Sci. Abs.*, 1960, **14,** Feb. 15, 354) Materials and methods, currently used in the aircraft and missile industry, to arc- and resistance-weld various steels are described. Design testing and inspection techniques are also considered.

Stud welding of low-carbon steels G. Fipps (*Avtom. Svarka*, 1960, (5), 38–43) Conditions for each type of stud and the relation between the conditions of the operation and the size of the studs are tabulated. Care should be taken that no burrs or other inequalities are left on the surfaces after pressing as the current will flow through them, thus weakening the joints.

Welding of rails F. Dufek (*Zváranie*, 1960, **9,** (8), 221–223) [In Slovak] Welding developments in rail carriage repair work, but mainly in the laying of silent, welded rails are discussed with special reference to Czechoslovakia.

Welding in rail laying S. Kříž (*Zváranie*, 1960, **9,** (8), 230–233) The utilization of welding in rail laying is discussed with special reference to Czechoslovakia, where considerable lengths of all-welded rails have been laid in recent years.—P.F.

Welding problems in railway carriage maintenance E. Emperger (*Zváranie*, 1960, **9,** (8), 223–227) Various welding problems encountered in repair work on railway carriages and locomotives are discussed. Considerable new scope for the use of automatic welding equipment is shown to exist.—P.F.

Welding and welding up casting cavities of Kh20N3G3D2L steel in a carbon dioxide atmosphere N. I. Kakhovskii and A. M. Ponizovtsev (*Atom. Svarka*, 1960, (3), 12–18) To ensure the required mechanical properties of the deposited metal when welding or welding up casting cavities in this ferritic–austenitic wear-resistant steel it is necessary that the deposited metal should contain not less than 30% of the austenite phase. For this purpose, powder wire or the solid type electrode 08Kh20N5G3D2 should be used. In the manufacture of hydraulic turbines the most efficient method of mechanizing the operation is by semi-automatic welding in a CO_2 atmosphere.

Automatic and semi-automatic machines for CO_2-welding K. Rejchlík (*Zváranie*, 1960, **9,** (9), 256–257) [In Czech] Equipment of recent Czechoslovak manufacture is shown and its scope discussed.—P.F.

The heat resistance of austenitic–ferritic deposited metal V. N. Zemzin, E. M. Pivnik, and N. A. Eroshkin (*Avtom. Svarka*, 1960, (3), 34–45) An austenitic–ferritic (up to 5% of α-phase) deposit metal alloyed with Mo and V (1Kh19N12M2F; electrode KTI–5) and with Nb (1Kh19N9B; electrode TsT–15) maintain sufficiently stable properties for over 100000 h service up to 600°. Deposited metal alloyed with Mo and Nb (2Kh19N9MB; electrode KTI–12) containing up to 9% of α-phase may be used for service up to 650°. In long-term ageing of the deposited metal at room temp., structure transformation takes place due to the decay of the α-phase.

The effect of the ferritic component on the formation of the σ-phase in the deposited metal N. Ya. Karasik and N. E. Shlepyanova (*Avtom. Svarka*, 1960, (3), 46–50) Investigation of three types of deposit metal differently alloyed and with different original ferritic phase contents have shown that the σ-phase in the metal alloyed with Mo and V (1Kh19N12M2F) is formed via the intermediate phases of the cubic type $Me_{23}C_6$ and of the σ-phase. With an increase in the original ferrite content, the domain of the intermediate phases shrinks under all thermal conditions. The dominant phase becomes the σ-phase, the proportion of which attains 16%.

Causes of cracking in high strength weld metals A. J. Jacobs, R. P. Sopher, and P. J. Rieppel (*WADC Techn. Rept.*, 52–322; *AD*–65474; *PB* 145332, pp.35; from *US Res. Rep.*, 1960, **33,** May 13, 547) Results from hot-tension and weld-metal cracking tests on SAE 43XX-type and other selected steels showed a correlation, as an increase in C, S, and P tended to lower hot ductility and promote hot-crack susceptibility, and a misch metal addition seemed to have the opposite effect.

Soldering stainless steels D. C. Stock and W. J. Smellie (*Weld. Met. Fabr.*, 1960, **28,** April, 160–161) This note briefly describes the development of corrosion-resistant joints. Joints made in stainless steel using conventional ternary and quaternary silver solders fail by interface corrosion in tap water. The mechanism of this type of corrosion is investigated and details of a new corrosion-resistant silver solder are given.

Brazing nickel-containing alloys and stainless steels J. Hinde and E. R. Perry (*Weld. Met. Fabr.*, 1960, **28,** April, 145–154) This article describes techniques used in brazing various nickel base alloys heat-resisting, low expansion alloys, austenitic stainless steels, and plain Cr stainless steels. Problems arising during brazing are dealt with, with special reference to the parent material, the complexities of the parts to be formed, the heating methods available, and the suitability of brazing alloys already developed. Finally, an account is given of the development of a range of new Pd-containing brazing alloys which offer certain outstanding advantages.

Ductility of brazed stainless steel joints H. A. Saller (*BMI*–847, 1959, Nov., pp.8; from *US Res. Rep.*, 1960, **33,** May 13, 587) No abstract.

Nickel–chromium–germanium alloys for stainless steel brazing J. A. McGurty and E. S. Funston (*USP* 2901347, 1959, Aug. 25; from *Nucl. Sci. Abs.*, 1960, **14,** April 15, 842) The ternary brazing alloy described contains 37–65 wt·%Ni, 5–40 wt%Cr, and 15–40 wt%Ge.

Productivity of carbide-tipped woodworking tools increased through induction brazing (*Ind. Heat.*, 1960, **27,** April, 734–738) A hf induction heater made by G.E.C. is used to braze carbide tips on router bits and on saw teeth. A variable coupling output transformer is used to vary the heat available. Brazing takes 45 sec per cycle, of which 10 sec are at max. temp. By comparison with previous methods, output is higher, and quality is improved and more uniform.

New oxygen cutting machines in the Brno Exhibition P. Šubrt (*Zváranie*, 1960, **9,** (9), 253–255) [In Czech] Photographs of several oxygen cutting machines of Czechoslovak manufacture, exhibited at the International Engineering Exhibition in Brno, Czechoslovakia, this year, are shown, and their characteristics discussed.—P.F.

A selective photoelectric relay for the control of oxygen cutting of hot steel K. Golgbiowski (*Prace Inst. Hutn.*, 1960, **12,** (3), 158–166) Two prototypes of selective photoelectric relays with K cells have been designed, discussed, and built. They observe the process of cutting which takes place at about 1500°C. The dc relay was found to be more sensitive and could work with higher power servo-relays.

MACHINING AND MACHINABILITY

Your machining setups may be obsolete R. T. Hook (*Steel*, 1960, **146,** April 25, 114) The achievements of three materials in improving tool life and cutting speeds are described. Ceramics have been found especially useful as high-speed finishing tools and for hard and abrasive metals. Improved high-speed steels are available. Tool materials containing up to 80%TiC have given excellent performance.

Practical application of theory to machining of stainless steels G. J. Stevens (*Machine Shop Mag.*, 1960, **21,** Nov., 703–706) A general account of steel properties, machining factors, chip removal, and cutting fluids with diagrams and a table summarizing the data.

Some applications of electrical resistance strain gauges and machine tools A. J. P. Sabberwal (*Manch. Assoc. Eng.*, 1960–1, (2), 1–26) Work on cutting, milling, and impact testing is referred to.

Systems and methods of controlling surface finish at the Ansaldo Engineering Works L. Cavazzoni and P. Delfanti (*Ing. Mecc.*, 1960, **9,** Sept., 45–55) After a description of the various surface finishes produced by methods of machining, the irregularity of the surface finish is defined. Methods of checking irregularity are described and compared.

Machinability of steels and cast iron during cutting with carbide-tipped tools G. D. Khaet (*Metallov. Obra. Met.*, 1959, (2), 49–53) Details are given of the parameters of the cutting tips which have given optimum results, in association with correct cutting regimes.

Workability (*Aciers Fins Spéc.*, 1960, July, 52–60) The various attempts at defining machinability are critically reviewed. The main factors influencing machinability are composition, process and method of making, orientation in relation to cutting direction, heat treatment, inclusions, and additions of soft metals.—R.P.

Effects of lead addition on the lathe cutting process R. Mennell and F. L. Bagley jun. (*RPL*–23/8; *PB* 145379, 1959, Oct., pp.25; from *US Res. Rep.*, 1960, **33,** June 17, 670) Lead additive acting as lubricant in tool chip interface explains effects of lead addition below critical speed.—S.H.-S.

New tool life formula gives higher accuracy B. N. Codling (*Metalw. Prodn.*, 1960, **104,** Oct. 26, 82–83) A new formula is advanced to replace that of F. W. Taylor.

U.S. research in ultra-high-speed machining —3 (*Metalw. Prodn.*, 1960, **104,** June, 977–983) Test results given in this, the last, report on American research into ultra-high-speed machining show that velocity, not cutting force, determines horse-power requirements. There also appears no evidence that the amount of heat rises in proportion to velocity —so that tool temp. does not increase indefinitely.—S.H.-S.

A study of the process of cutting at very high speeds V. D. Kuznetsov, G. D. Polosatkin, and M. P. Kalashnikova (*Fiz. Met. Metallov.*, 1960, **10,** (3), 425–434) A laboratory installation is described which made it possible to study the process of cutting metals at speeds of 100–700 m/s. The process was found to be very different from the cutting of metals at industrial speeds (8 refs).

Considerations regarding the cutting parameters of tools made of Rumanian high speed steel M. Popov, I. Mitrica, and E. Deciu (*Mecanica Aplicata*, 1959, **10,** (2), 539–564) It is possible to calculate the geometrical parameters of steel cutting tools which give a relatively slow rate of wear. These optimum values are independent of the nature of the steel. This fact is a further confirmation of the hypothesis that optimum geometrical parameters of the cutting tool are practically independent of the material of the tool provided it is of sufficient hardness.

Chill puts new life in tools General Dynamics Corp. (*Steel*, 1960, **146,** May 2, 66–69; *Iron Age*, 1960, **185,** May 19, 160–161) The results of machining trials on high-strength, high heat-resistant alloys using 'subzero cooling' techniques are described. The three techniques

were: cooling with CO_2 mist; cooling with a flood of refrigerated liquid; refrigerating the workpiece. In the first two methods temp. of −50° to −100°F were applied to the work during machining. Several alloys and machining operations were tested, and advantages resulted in some cases. Compared with machining at room temp., tool life was increased by up to 400%, but microstructure and mechanical properties of the workpiece were not affected.

Double carbide saw steel reduces bar cutoff time Capewell Manf. Co. (*Steel*, 1960, **148,** April 25, 127) A new 'double carbide' alloy steel has been developed especially for bandsaw blades. The hot hardness and abrasion resistance allow high blade and feed speeds and the sawing of hard materials.—D.L.C.P.

Is this the answer to cutting superalloys? Sub-zero machining F. A. Monahan (*Metalw. Prodn.*, 1960, **104,** Oct. 5, 83–91) Tests carried out by Convair for the US Govt. are described. Mist cooling with CO_2 improves tool life by as much as 300% and flood-cooling at −76°F is especially good for turning and drilling superalloys. An austenitic stainless and a hot work die steel were included in the tests.

Numerically-controlled milling: Faster and more accurate J. Daugherty (*Iron Age*, 1960, **185,** May 5, 78–89) The arrangement of a numerically controlled milling system is described. The sequence of events is—blueprint translated into blocks of figures by engineers; details coded and put on to punched cards; computer converts code into co-ordinate data; data translator transfers instructions on to tape; tape is fed to a director which converts decimal numerical data into time-co-ordinated electrical signals which are fed to milling machine. This process can be effected very rapidly.—D.L.C.P.

Test of diamond abrasive needles shows advantages Engelhard Hanovia Inc. (*Steel*, 1960, **147,** July 18, 102) Tests of a natural diamond abrasive material for grinding wheels, 8ND–Rb (Needle), are reported as producing good results in resinoid wheels at light to moderate infeeds.—S.H.-S.

Precision grinding research H. Grisbrook (*J. Inst. Prod. Eng.*, 1960, **39,** June, 341–346) This is the second part of a paper on research into precision grinding carried out by the Univ. of Birmingham, Department of Engineering Production, on a Churchill 8 in × 16 in plain surface grinding machine. The findings indicate that the mechanism of grinding takes two forms. The first under conditions of high metal removal is one predominantly of cutting and in the second as the rate of metal removal approaches some critically low value, rubbing predominates.

High speed grinders speed 50% more castings on way K. J. Easter (*Steel*, 1960, **147,** July 4, 84) The improved output and quality, and economy gained by replacing a 12 000 rpm grinder by a 18 000 rpm unit are presented.

Manual on throw-away tooling (*MP* 00–193, *PB* 161276, 1959, July, pp.89) This manual describes the benefits which can be derived from replacing brazed carbide cutting tools with throw-away type tooling. The methods used in converting to a throw-away tooling system are described with the aid of graphs and charts. Cost reduction methods directly associated with the introduction of a throw-away tool system are described.

Deposited film obscures true wear measurement of ceramic tools A. Gibson (*Metalw. Prodn.*, 1960, **104,** June, 983–985) It is suggested that earlier beliefs about the non-welding properties of sintered Al_2O_3 cutting tools are definitely incorrect, and that, under some conditions, a strongly attached film or layer can form on the flank of a tool—a film difficult to detect and giving a false impression of the true value of the wear land. Examples are given.

Steel inserts add strength to laminate tooling H. L. Hildebrand (*Iron Age*, 1960, **186,** July 7, 86) The use of steel inserts in laminated plastic, at the point of high stress, is shown to fit the material for machining operations at low cost, giving repeated use and the elimination of the need for final finishing.—S.H.-S.

Wear land measured without removing tool I. Hans and J. Stanislao (*Metalw. Prodn.*, 1960, **104,** April 20, 702–703) A modified Brinell microscope attachment with a 35 mm camera mounted on top of the eyepiece enables tool wear to be observed and measured and a permanent record to be made without removing the cutting tool from the test lathe. Other adaptations and uses are also presented.

A study of standard clearance hole sizes, positional tolerances and drill size selection for steel and cast iron C. I. Millard (*SCTM*–133–56 (16), 1957, Jan., pp.25; from *Nucl. Sci. Abs.*, 1959, **13,** Feb. 28, 284) Standard clearance hole sizes for the common screw fastener sizes, positional tolerances, and assembly applications were established.

Machining by electro-erosion M. Robert (*Rev. Inf. Fed. Royale. Assoc. Ingen.*, 1960, Sept.–Oct., 420–434) The writer describes the history of the process and attempts an explanation of the phenomenon of electro-erosion. The advantages of spark-erosion machining are listed as reduction in production costs, possibility of using non-specialist labour, shorter processing time, easier repair of worn matrices, extension of production range, machined metal free from structural changes, increased fatigue resistance and absence of traces of machining.

Five economical ways of producing large spark-erosion electrodes W. Ullmann (*Metalw. Prodn.*, 1960, **104,** Aug. 3, 53–56) Machining, press forming, spraying, electroplating, and casting may all be used. The fields of application of these methods are discussed.

CLEANING AND PICKLING

Efficient cleaning R. H. Herrmann (*Foundry*, 1960, **88,** May, 156–160) The arrangement of a modernized cleaning room for low-alloy steel castings is described. In two shifts the room handles 85-t of castings weighing 1 to 1 000 lb in job lots.—D.L.C.P.

Surface treatment of stainless steels S. Colombo (*Acciaio Inossid*, 1960, **27,** (4), 461–465) Various methods are described with special reference to surface washing and degreasing by alkaline solutions and other solvents.

Replacement of a cleaning shop without loss of production John Smith Ltd (*Wire Ind.*, 1960 **27,** April, 371–374) A modernization programme is described in which eight tanks in a wire pickling plant were replaced and other equipment introduced without loss of production.—D.L.C.P.

Stainless tubing gets dip in ultrasonic bath S. Rubenstein (*Iron Age*, 1960, **186,** July 21, 134–135) The ultrasonic wave motion, set up in the cleaning solution, increases its physical and chemical soil-removing action and drastically reduces cleaning time. Its use is briefly described.—S.H.-S.

The present position regarding surface cleaning by blasting J. H. Zaat (*Metalen*, 1960, **15,** Aug. 31, 277–279) This is a summary of a paper, read by the author before the Association of Dutch Foundries, which is based on the results of the investigation already reported in *ibid.*, 1958, **13,** (3, 4, and 5).—F.R.H.

Link cleaning and degreasing to production machining Metalclean Equipment Co. (*Iron Age*, 1960, **185,** May 5, 84–85) An automatic cleaning and degreasing machine is described which deals with parts as they come from machine tools or vibratory hoppers; it is called 'AutoSonex'. The essential parts are four rotating wheels with 'cubicles' round the internal periphery; parts are conveyed in the cubicles until they fall into the next wheel or the exit chute. The four stages are: clean in solution with ultrasonic waves; rinse, drain, and dry. Solvent degreasing can be included if required.—D.L.C.P.

Composition for rapid and simultaneous de-rusting, degreasing, and rust-proofing of ferrous surfaces at ambient temperatures M. H. Swann (*AD*–155258; *PB* 145043, 1958, Jan., pp.11; from *US Res. Rep.*, 1960, **33,** May 13, 548) A formula composed of ethylene glycol monobutyl ether in a water-soluble, acid-stable non-ionic surface-active agent used in aqueous medium containing H_3PO_4 and ferric oxalate was developed, which can be supplied in concentrated form for dilution with H_2O to facilitate shipping and storing, exhibiting, an accelerated rate of rust removal.—S.H.-S.

Removability of oxide scale from steel plate F. K. Peters (*J. S. Afr. IMM*, 1960, **60,** July, 688–708) A study of the removability of mill scale from unalloyed steels cast unkilled, or killed with Si and Si + Al, and then rolled to plate of 10–27 mm thickness at rolling temp. of 1 050–650°C. The mechanical adherence has been determined by a method specifically developed for this purpose. With unkilled steels, adherence decreased as rolling temp. increased. With killed steels no clear correlation was observed. Laboratory results generally agreed with actual practice.—S.H.-S.

Two alkaline cleaners can handle most jobs P. Welsh (*Steel*, 1960, **147,** July 11, 96–98) The relative uses of a low alkalinity cleaner and a heavy duty (caustic) cleaner are summarized and compared.—S.H.-S.

Ultrasonic agitation gives new life to pickling and cleaning baths H. F. Osterman and A. V. Santa Lucia (*Met. Prog.*, 1960, **78,** Aug., 110–114) The large-scale application of ultrasonic cleaning and pickling is described with examples. Comparison of costs in flash pickling and ultrasonic cleaning were made for a theoretical shot-blast cleaning line for strip and showed a considerable cost advantage for the ultrasonic process.

Ultrasonic pickling cleans turbine engine parts Avco Corp. (*Iron Age*, 1960, **185,** April 28, 114–115) The use of a pickling unit which cleans parts in 30 sec is described. Ultrasonic vibrations in hot 30% H_3PO_4 are employed.

Inhibition of hydrogen embrittlement during pickling L. Dauerman (*PB* 145503, 1959, pp.38; from *US Res. Rep.*, 1960, **33,** May 13, 545) Phenomena at metal-acid solution interfaces; hydrogen diffusion with possible roles of hexamine and DHQ are reported.—S.H.-S.

Cathodic cleaning of metals before high-temperature oxidation D. E. Davies and S. N. Shah (*Nature*, 1960, **188,** Oct. 8, 138–139) A letter. Work on tin is described. A more complicated mechanism than simple oxidation film formation is indicated.

Precision parts electro-deburred in seconds (*Metalw. Prodn.*, 1960, **104,** April 20, 699–701) Electropolishing of cathode ray tube components for the removal of minute burrs, drawing marks, and oxidation by an MEPP installation at Standard Telephones and Cables Foots Grey plant, is described.—S.H.-S.

Rotary polisher made fully automatic B. O. Morris Ltd (*Metalw. Prodn.*, 1960, **104,** June 22, 257–259) An installation with continuous feed, automatic load and unload, and a mop wear compensating device is described.

Modern ideas on the mechanical polishing of metals L. E. Samuels (*Research*, 1960, **13,** Sept., 344–349) Classical and modern theories of polishing are reviewed. The Beilby layer is not now believed to exist and the new concept of polishing by a cutting process is set out.

PROTECTIVE COATINGS

New-style layout for electroplating D. Fishlock (*Metalw. Prodn.*, 1960, **104,** Oct. 5, 74–75) An illustrated account of the shop installed by W. Canning & Co. for S. Smith & Sons Ltd at Cheltenham. Sn, Sn–Ni, Ag, and Cd-plating will be carried on.

Metallic coating by electrolysis (*Galvano*, 1959, **28,** Dec., 571–575) The article discusses modern problems and trends in plating techniques. The form of the object coated is very important for the even distribution of the coating and close co-operation between designer and plater is considered desirable. Different methods of electrolysis are then described. Corrosion tests are dealt with and the phenomenon of corrosion under Cu, Ni, and Cr-plating is discussed.

Measurement and stress in electrodeposits (*Austr. Mach. Prod. Eng.*, 1960, **13,** April, 47–49) The measurement of stresses in a direction parallel to the plated surface in the cases of Cr, Ni, and Zn deposits is briefly considered.

Continuous and batch treatment of industrial wastes E. F. Druschel, J. F. Zievers, and W. Zabban (*Met. Fin.*, 1960, **58,** March, 58–63, April, 66–70) The design and operation of detoxification plant for the treatment of plating, mechanical finishing, heat-treatment, and painting effluents at the IBM Corp. electric

typewriter works, Lexington, Kentucky, is described.—A.D.H.

Chromium electroplates for corrosion protection of stressed AISI 410 in high temperature, high purity water H. Suss (*KAPL–M–HOS–8*, 1959, Sept., pp.29; from *US Res. Rep.*, 1960, **33**, June, 17 713) No abstract.—S.H.-S.

Chromium plating on nodular iron piston rings N. A. Solov'ev (*Vestnik Mashin.*, 1955, **35**, (7), 75–77) A method of porous plating is described, and cleaning, inspection, testing, and finishing are also dealt with, and the defects encountered and methods of dealing with them including stripping and replating are added.

Nickel plating in nickel sulphamate baths (*Rev. Nickel*, 1959, **25**, Nov.–Dec., 154–155) The development of the nickel sulphamate bath process is briefly summarized. Its advantages are: plating without internal pressure, the possibility of high current density, little trouble from impurities, the coating of nickel is extremely pure, it is easy to control and maintain and the bath is of simple composition. The physical properties of the coating are easily transferred and the stress-resistance of the basis metal is improved. The grain size is good and the metal is very ductile.

Double nickel-plated layers retard corrosion, add life L. V. Nagle (*Iron Age*, 1960, **186**, July 14, 110–111) A new semi-bright nickel plating process, producing a sulphur-free deposit, and designated N2E by the Udylite Corp., Detroit, for which certain advantages are claimed, particularly good adhesion, is presented.—S.H.-S.

Some problems of an accelerated nickel plating process L. Domnikov (*Met. Fin.*, 1960, **58**, March, 44–47) The author summarizes recent Russian work dealing with accelerated deposition of Ni from a solution containing 80 gm/l $Ni(NH_4)_2(SO_4)_2$. The bath gave satisfactory bright deposits using a reversed current method, when passivation of the cathodic surface occurred during the anodic part of the cycle. X-Ray studies showed that deposits whose cubic plane was parallel to the plane of the basis metal were dull and formed under conditions favouring cathodic polarization (27 refs).—A.D.H.

Bright nickel deposits by the use of hexamine, cystine and fumaric acid as addition agents A. Jogarao and S. Guruviah (*J. Sci. Ind. Res.*, 1960, **19B**, Feb., 84–85) A letter. The results of tests carried out at room temp. for 15–30 min with addition agents are compared favourably with those from a stock solution.—S.H.-S.

Cystine as addition agent for 'bright' zinc deposits from the acid bath A. Jogarao and S. Guruviah (*J. Sci. Ind. Res.*, 1960, **19B**, Feb., 85–86) A letter. Tests similar to those adopted by the authors for bright Ni deposition in the previous abstract are described as of a lower order of brightness than that obtained with nickel.—S.H.-S.

Plating reclaims costly parts Goodyear Aircraft Corp. (*Iron Age*, 1960, **185**, May 5, 86) The operation and applications of the Dalic Selective Plating Process are described. The method can apply controlled-thickness coatings of Ni and other metals by electrolytic deposition from a pad soaked in solution. Thus selected areas of parts *in situ* can be treated for reclamation or other purposes.—D.L.C.P.

Converting plating line need not be costly Middleville Engineering & Mfg. Co. (*Steel*, 1960, **147**, July 4, 72) The reasons for converting a single Ni (one coat) plating system to a bi-nickel (two coat) process and its operation is explained.—S.H.-S.

Standardization and thickness control of nickel coatings J. Grilliat (*Rev. Nickel*, 1960, **26**, March–April, 41–50) This article describes the standardization of Ni coatings, various methods of measuring their thickness, factors governing the choice of thickness and the choice of a method of its control. The recommendations are tabulated.

Fully-automatic plating meets flexible work schedules J. N. Kelley (*Iron Age*, 1960, **185**, May 26, 102–103) Features of a plant applying zinc coatings to parts are described. A fully automatic barrel plating machine is employed.

A new squeegee machine for hot tin-plating plants I. S. Sukhov (*Stal'*, 1960, (9), 833–834) The design is described and discussed.

The spread of molten tin on mild steel reduced in hydrogen or treated with molten fluxes E. T. Turkdogan and S. Zador (*JISI*, 1961, **197**, March, 233–239) [This issue].

Rapid cold Parkerizing of ferrous metals Tien Yü-liang, Liu Tien-shian, and Yuan Ping-chien (*Electrotechnik*, 1958, (11), 19–21; from *Sci. Abs. China, Techn. Sci.*, 1959, (1), 47) A process employed by the Harbin Electric Instruments Co. is presented as being superior to conventional hot process. Technological details and specifications are given.

Science for electroplaters. 55: Copper cyanide analysis L. Serota (*Met. Fin.*, 1960, **58**, March, 66–68) Methods are given for the determination of Cu, free NaCN, carbonate and Rochelle salt in copper cyanide plating solutions. **56: High efficiency copper cyanide** (April, 76–79) The formulation and operation of the high-speed copper cyanide, copper-amine, and pyrophosphate baths are discussed.—A.D.H.

Electrolytic deposition of manganese G. Scacciati (*Met. Ital.*, 1960, **42**, Aug., 551–560) The electrochemical and technological problems involved in the electrolytic deposition of Mn and the electrolysis conditions which arise are discussed. The operation for one year of a pilot plant producing 100 kg of metal daily is described and the cell with diaphragm used in this plant is illustrated and compared with similar plant.

Vapour-phase method plates high-melting refractories Alloyd Corp. (*Iron Age*, 1960, **185**, April 28, 112–113) Recent achievements of the 'Alloyd' process are described. The process involves the controlled decomposition of organometallic compounds or the reduction of metal halides. Metals such as Mo, W, and Cr and their refractory compounds can be coated on a variety of base materials at temp. as low as 250°C. Coatings have excellent adhesion and are non-porous.—D.L.C.P.

The effects of surface preparation for metal-spraying on the adherence of sprayed coatings I. Mano (*Nippon Kinzoku*, 1959, **23**, Sept., 503–505) Results from a JIS bending tester are given. For sprayed zinc coatings, there is a linear relationship between adherence and surface roughness. The curve of adherence against exposure time is parabolic; spray coatings should therefore be applied within 150 min of blasting. The influence of exposure time is less marked with fine than with coarse blasting.

Advances in industrial metallising with molten metals and electrolytes J. Teindl (*Hutn. Aktuality*, 1960, **18**, 1–77) [In Czech] Modern processes of galvanizing, tinning, coating with lead, etc., are reviewed in detail.—P.F.

Conversion coatings: Oxide films L. F. Spencer (*Met. Fin.*, 1960, **58**, April, 62) Notes on black oxide films on iron and steel and their properties.

Anodization of steel in a fluoride bath H. F. Priest and M. Levitz (*TID–5090*, pp.2; from *Nucl. Sci. Abs.*, 1960, **14**, April 15, 843) Motor laminations are anodized in a fused salt bath using a steel cathode, to protect them from UF_4 attack.

Chromate conversion coatings C. W. Ostrander (*Mat. Des. Eng.*, 1960, **52**, Aug., 116–120) A review of the properties of these coatings on ferrous and non-ferrous metals with an outline of application methods and a list of tests.

Automated line phosphates bearings (*Steel*, 1960, **147**, July 18, 86–87) Corrosion protection for tapered roller bearings used on railway rolling stock is provided by an automated phosphating line at the Timken plant at Columbus, Ohio, and processes 160 000 bearings a year. Sequence of operation is illustrated.—S.H.-S.

Stress phenomena in enamelling M. F. A. Hoens (*Chem. Weekb.*, 1960, **56**, July 30, 453–461) The article deals with the stress phenomena which occur during the expansion and contraction of the enamel particularly when enamelled articles undergo rapid cooling in air. A distinction is shown in the behaviour between crystalline and non-crystalline materials. The shrinkage differences lead to stresses depending on the elastic moduli, thicknesses, shape, etc. The stresses can cause deformation and methods of measuring these are discussed. To conclude, the article also points out stress phenomena attributable to impurities either in the enamel or in the base material.—F.B.H.

Enamel pre-coating followed by vacuum metallizing is economical finishing technique (*Ind. Heat.*, 1960, **27**, April, 804–810) The Plastic Dress Up Co. is coating both metallic and non-metallic products with ferrous or non-ferrous metals (mainly Al). The extreme cleanliness of the parts, essential to the final finish, is ensured by placing the parts on fixtures (to eliminate later handling) and applying a thin enamel coating, which is then baked before the vac. metallizing process.—K.E.J.

Process bonds glass to steel for designing versatility O. J. Britton (*Iron Age*, 1960, **185**, May 12, 144–145) The production and application of glassed (glass lined) steel are described Glass powder is either hot-dusted or wet-sprayed on to the steel surface and then fused; this may be repeated up to seven times. The strength of steel is added to the advantages of glass for handling corrosive, sticky, or ultra-pure materials. Uses include reactors, dryer-blenders, columns, storage tanks, valves, and piping.—D.L.C.P.

Influence of steel silicon content on the formation of 'fish scales' in enamel F. Erdmann-Jesnitzer and A. Petzold (*Arch. Eisenh.*, 1960, **31**, Aug., 479–484) H_2 content and susceptibility to fish scaling were examined in sheet steel with 0·04–3·5%Si, the composition being otherwise kept constant. H_2 permeability decreases with increasing Si content, and is practically zero at 3·5%Si. Maximum fish scaling occurred at 0·1–0·2%Si. It disappeared with Si contents of 2·5–3·0% (23 refs).

An investigation on the properties of numerous rust preventive ship bottom coatings H. W. Talen, W. J. Pfeiffer, and A. M. van Londen (*Metaalinst. TNO Report* 74 and *Circular* 94, June, 1960, pp.15) The results are given of an investigation started in 1953 on the properties of a number of rust-preventive ship bottom coatings applied to steel plates immersed in sea water. They comprised 45 different coatings and included two commercial products, the remainder being test coatings containing 15 different binders and 12 colorants. From this first series of tests it was found that 12 showed promise. Part II of the report deals with the practical tests carried out with coatings applied to the hulls of ocean-going vessels and examined a year or so later on the return of the latter from their voyages.—F.B.H.

Mode of action of soluble matrix antifouling compositions A. Partington (*Nature*, 1960, **187**, Sept. 24, 1105–1106) A letter. Agitation of sea water in leaching rate determinations leads to a reduced rate which is not related to Cu_2O content.

Automation speeds paint dipping at Tappan (*Steel*, 1960, **147**, July 18, 104–105) Improvements resulting from the installation of a new automatic, flying shear line are reported.

Continuous dip paint system installed at Chrysler plant for finishing frames of new Unitized automobile bodies (*Ind. Heat.*, 1960, **27**, April, 799–802) 400 Stub frames per hour are conveyed from the automatic loading station through the washer, two-pass drying oven, cooling area, paint dip tank, drip area, and three-pass baking oven, to the automatic unloading station.—K.E.J.

CLAD SHEET AND HARD FACING

Thin clad sheet (*Aciers Fins. Spéc.*, 1960, July, 78–81) Economic and technical aspects of clad sheet are discussed and their main uses are summarized.—R.F.

Automatic face hardening of a hydraulic rotating turbine blade by electrode strip under flux F. A. Komus'ko and B. A. Rabotnov (*Avtom. Svarka*, 1960, (1), 62–71) A method is explained of preparing a turbine blade by welding on a protective layer which should considerably increase its service life. The operation is automatic, with strip electrodes under a suitable flux.

Iron protection by case hardening or sprayed metal siliconisation and titanisation of iron, nickel and copper (*Galvano*, 1960, **29**, April, 221–224) The conclusions are that the only surface reaction which has a uniform mechanism and consequently is thermodynamically determinable is siliconization of iron in an argon atmosphere and titanization of Ni with

$TiCl_3$. These offer advantages over known methods of improving surfaces provided a quantitative study is first made of the chemical, thermodynamic and kinetic principles of the corresponding reactions.

Hard metallic plating. Hardness curves in chromium plating as a function of the temperature and current density G. Rousselot (*Galvano*, 1959, **28**, Dec., 585–588) This study aims at establishing the curves for a chromium bath of composition 250 g/l CrO_3, −2·5 g/l H_2SO_4, another to establish similar curves for baths of varying concentrations, 300 g/l CrO_3 − 3·5 g/l H_2SO_4 and 350 g/l CrO_3 − 3·5 g/l H_2SO_4. A 30 l tank was used and 80 × 25 mm test pieces of steel plate. It is concluded that the two bright and matt areas are very small compared with the dark and 'iced' zones. The increase in hardness is very rapid and corresponds to a matt chromium zone.

Brilliant and hard chromizing J. Stepanian (*Tratt. Term. Met.*, 1960, **3**, May–June, 3–8) Hardening by Cr or chromizing of steel can solve simply and economically the problem of surface wear and corrosion and often gives better results than conventional methods. The technique of chromizing by diffusion, the characteristics of chrome diffusion layers, and the uses of chromizing in dental surgery are described.

Gas plating duplicate contours without machining Budd Co. (*Metalw. Prodn.*, 1960, **104**, June 29, 107–108) Hard-facing with $Ni(CO)_4$ at 280°F is used.

Diffusion processes in bimetal 'steel–aluminium alloys' during heat treatment A. D. Kuritsyna, F. V. Korolev, and K. N. Korsunskaya (*Metallov. Obra. Met.*, 1959, (2), 2–7) Al-clad steel strip, used for the liners of engines is manufactured under conditions which prevent separation at the diffused layer of the Al and steel.

Production of a pore-free ferrosilicon layer Y. Mittani and M. Onishi (*Nippon Kinzoku*, 1959, **23**, May, 273–276) [In Japanese, with German summary] The diffusion method of producing a FeSi layer produces fewer pores the higher the process temp. and the shorter the time. At 1180°C for 20 min, a pore-free layer can be produced, 0·3 mm thick, on the surface of 0·4%C steel.—K.E.J.

Glass-bonded refractory coatings for iron- or nickel-base alloys T. E. Cook and B. W. King (*DMIC–Memo–16*, 1959, April, pp.18; from *Nucl. Sci. Abs.*, 1959, **13**, Aug. 31, 1949) A review of ceramic coatings, compositions, and methods of application (40 refs).

POWDER METALLURGY

Metal sinterings B. P. R. Parsons (*Financial Times*, 1960, July 27, 7) An introductory note to the section on powder metallurgy.

Powder metallurgy: expanding role in the component field P. R. Marshall (*Financial Times*, 1960, July 27, 7) Costs and processes are briefly considered.

How the powders are made (*Financial Times*, 1960, July 27, 8) A non-technical account.

What to consider in design (*Financial Times*, 1960, July 27, 7) Notes on powder metallurgical requirements.

Electrolytic preparation of an iron powder for magnetic uses on a mercury cathode G. Dan and O. Ivanciu (*Studii si Cercetari Met.*, 1960, **5**, (1), 111–120) A comparison is reported between iron powders obtained on a mercury cathode and on a metallic plate cathode. Regarding purity, both products are of a similar standard, 99·99%. Spectrographic analysis has not yet revealed foreign substances. The only contamination was due to the metallic cathode or to stainless steel, the anode dissolving in the mercury cathode deposit. The grain size however is very different in the two methods. On the metallic cathode the grains can be distinguished under a microscope after crushing the deposit, while the crushed mercury crust gives 1–5 micron grains and also grains below 1 micron. The micropowder can easily be separated by an electromagnet. The mercury cathode powder is very sensitive to heat so that the grain size may be controlled with slight heating.

Protection against corrosion by layers of powdered metal V. Marcu, N. Zelingher, and P. Freund (*Mecanica Aplicata*, 1958, **9**, (2), 457–470) It is well known that metallic surfaces can be protected against corrosion by layers of powdered metals anodic or cathodic to the protected metal. In almost 90% of cases the steel or iron surfaces are protected with Zn or Al which are anodic metals to iron. Al is especially recommended, having a smaller pH than zinc.

Study on the sintered Fe–Al–Ni system magnet. III. On the sintering of the 52·5Fe–11Al–18Ni–12·5Co–6Cu system K. Shida (*Nippon Kinzoku*, 1959, **23**, June, 315–318) The sintering process is similar to that of the Fe–Al–Ni system, but densification is accelerated by the addition of Co and Cu. At 1300° or 1350°C densification and pore shrinkage were nearly complete in 30 min, and were followed by rapid alloying. Sintering temp. has a greater effect than time on the alloy properties.

The effect of foreign substances on the strength of powder metal aggregates O. Zmeskal (*NP–7038*, 1958, Sept. 30, pp.1220 from *Nucl. Sci. Abs.*, 1959, **13**, Feb. 20, 284) The properties of metal oxide mixtures produced by the methods of powder metallurgy are described. The metal matrices covered are Cu, Ti, Zr, and Fe. For each metal the optimum conditions of particle size, method of aggregation, pressing pressure, sintering atmosphere and temp., and additional pressing and sintering operations were determined. The criteria used were density and hardness.

Influence of the protective gas atmosphere on the properties of sintered steel K. Wassmann (*Forsch. Wirts. Nordrhein-Westfalen*, 1959, (798), pp.94) The nature of the sintering process is examined critically, and it is concluded that the physics of sinter technique is essentially surface physics. The commonly-used protective gases are enumerated and compared, including their methods of preparation, storing, and testing. The mechanical strength of sintered iron and steel parts is examined as a function of their sintering in various gas atmospheres.

Carburizing and hardening of sintered iron tools H. Weiss (*Foresch. Wirts. Nordrhein-Westfalen*, 1959, (799), pp.61) A critical discussion of methods applicable to the hardening of sintered parts, both by admixture with carbon before sintering to obtain a hardenable structure and by gas carburizing. The importance of density in determining the properties of the sintered parts is shown.

Study on sintered Fe–Al–Ni system magnets. V. Effect of small phosphorus additions on the properties of sintered Fe–Al–Ni–Co–Cu system magnets M. Sugiyama and K. Shida (*Nippon Kinzoku*, 1959, **23**, Oct., 576–580) Up to a certain concn., P markedly improves the properties of the alloys prepared by sintering n pure H_2, viz. grain growth, density, transverse rupture strength, and magnetic properties. Larger additions, however, produce a P-containing eutectic which has a detrimental effect on magnetic properties.—K.E.J

Investigations on stainless steel- and titanium base dispersions E. S. Byron (*WAPD–TM–80*, 1957, Oct., pp.65; from *US Res. Rep.*, 1960, **33**, June 17, 716) No abstract.—S.H.-S.

Radiographic determination of lattice distortions on carbonyl iron powders A. Kochendörfer and F. Trimborn (*Arch. Eisenh.*, 1960, **31**, Aug., 497–502) Measurements, already carried out on two iron powders P and H with cobalt radiation, of the form and width of the lines were repeated with Mo radiation to show whether lines are measurable within three orders. It was found that, with the exception of the line (110) of powder P, only two orders of each of several lines could be measured, the higher orders being too weak. The results of a Fourier analysis for both powders are discussed and compared with previous findings (15 refs).

FERRITES, CERMETS AND CARBIDES

Vacuum sintering ensures quality of cemented carbides Jessop-Saville (Small Tools) Ltd (*Metalw. Prodn.*, 1960, **104**, July 27, 62) A brief note on the furnaces used to make dense cemented carbides.

Cemented hard metals—their basis in the particular reference to the tungsten-carbide cobalt system H. H. Doeg (*J. S. Afr. IMM*, 1960, **60**, July, 663–686) A review of literature dealing with the fundamentals of W-based hard metals. The manufacture of these alloys is briefly described and the physical metallurgy at all stages of the process is discussed in terms of the properties of the finished hard metal alloys.—S.H.-S.

Some special features of the multiplet ferromagnetic resonance in ferrites V. N. Lazukin (*Zhur. Exp. Teoret. Fiz.*, 1959, **36**, (3), 682–689) Preliminary findings from the observation of multiplet ferromagnetic resonance of inhomogeneously magnetized specimen of single and polycrystalline ferrites are reported. The inhomogeneous magnetization was produced by the uneven demagnetization of the specimens. The first results point to the fact that the multiplet ferromagnetic resonance is a rather complex phenomenon depending on a number of conditions and that its study should prove useful towards understanding the properties of the ferrites.

PROPERTIES AND TESTS

Temperature induced stresses in solids of elementary shape L. H. Adams and R. M. Waxler (*NBS Monograph* 2, 1960, June 21, pp.27) In general a solid subjected to non-uniform temp. change develops internal stresses. These are determined by (1) the temp. distribution within the solid and (2) certain physical constants of the material. For two varieties of heating the equations determining stress have now been put in convenient form and tables of certain temp. functions are offered as a means of quickly determining stresses in a slab, a cylinder or a sphere subjected to either of two heating methods. The temp.-distribution tables independently will provide a useful means for estimation of temp. gradients.

Investigation of the roles of absolute grain size and number of grains in the cross-section as factors controlling flow and fracture stresses at low temperature J. W. Hill (*AFOSR–TN–58–682*; *AD–162215*; *PB 138107*, 1958, Feb., pp.18; from *US Res. Rep.*, 1960, **33**, May 13, 548) Absolute grain size and not the number of grains in the cross-section is observed as the controlling factor in determining flow and fracture stress at low temp. when other factors are constant.—S.H.-S.

Measurement of surface stress in austenitic steel J. C. Moore (*Brit. J. App. Phys.*, 1960, **11**, June, 242–243) A method is described to evaluate macro-surface stresses in an austenitic steel. A multi-exposure, X-ray back-reflection technique is employed, and surface-stress values obtained by this method are compared with theoretical values.—S.H.-S.

Mechanical properties of steels for sodium service W. J. Anderson (*NAA–SR–4509*, 1960, March, pp.127; from *Nucl. Sci. Abs.*, 1960, **14**, June 15, 1367) The physical and mechanical properties of 18 alloy and stainless steels at room temp. to 1500°F are presented in the form of graphs to show the effect of temp., and prefacing each set of graphs is a listing of ASTM designations for the steel. Data on heat content, density, electrical resistivity, thermal expansion, thermal conductivity, short-time tensile properties, impact strength, creep strength, stress-rupture strength, and fatigue strength are included. Numerous sources are given, and relationships between service conditions and conventional properties are discussed.—S.H.-S.

Beam method for the measurement of internal friction J. E. Thompson (*J. Sci. Instr.*, 1960, **37**, June, 208–210) The oscillatory motion of a swinging beam, used to measure the internal friction of a silicon–iron strip, has been found to be complicated and to consist of a small-amplitude higher frequency oscillation superimposed on the main oscillation, so that difficulty arises in obtaining a unique value for the log decrement of the strip oscillation. The motion has been analysed and reasonable agreement is found between the experimental results and the theory developed.

Internal friction effects in iron–silicon–

nitrogen alloys R. Rawlings and P. M. Robinson (*JISI*, 1961, **197**, March, 211–215) [This issue].

Determination of the plastic properties of sheet steel from the results of hydrostatic testing L. A. Rubenkova (*Kuznechno-Shtamp.*, 1960, (6), 12–13) Hydrostatic testing makes it possible to assess the mechanical properties of sheet steel more thoroughly than other methods. Its many advantages are listed. It is therefore recommended for use in controlled experiments on stamping.

The ductility of brazed stainless steel joints H. A. Saller, J. T. Stacy, and N. S. Eddy (*BMI*–847, 1953, July, pp.8; from *Nucl. Sci. Abs.*, 1960, **14**, March 15, 581–582) At elevated temp. the ductility approximated that of the stainless steel but at room temp. the brazed joints had only 0·1 the ductility of the base metal. Annealing for 16 h at 1800°F was found to triple the room-temp. ductility of the brazed joint.

Study of factors influencing ductility of iron–aluminium alloys F. C. Perkins and J. F. Nachman (*TID*–5626, 1960, March, pp.7; from *Nucl. Sci. Abs.*, **14**, June 15, 1369) The effect of variations of Al content, heat-treatment, and other metallurgical factors upon the room-temp. ductility of Fe–Al alloys are reported.—S.H.-S.

Study of factors influencing ductility of iron–aluminium alloys: Monthly report No.6 F. C. Perkins and J. F. Nachman (*AECU*–4400, 1959, Oct., pp.9; from *US Res. Rep.*, 1960, **33**, May 13, 586) No abstract. **Report No.7** (*AECU*–4448, 1959, Nov., pp.8; from *US Res. Rep.*, 1960, **33**, May 13, 586) No abstract.

Study of factors influencing ductility of iron–aluminium alloys G. Rauscher (*AECU*–4335, 1959, Sept., pp.12; from *US Res. Rep.*, 1960, **33**, May 13, 585) No abstract.

Internal friction measurements on iron and steels T. Ichiyama, M. Kawasaki, K. Takashina, S. Saikawa, and F. Kusama (*Nippon Kinzoku*, 1959, **23**, July, 418–422) Data are given for damping and other peaks found in vac-melted electrolytic iron with low N content, vac-melted electrolytic iron treated with wet H_2, Armco iron, and medium- and high-C steels (19 refs).—K.E.J.

Effect of heat treatment on the Snoek damping peak in Armco iron T. Ichiyama, K. Takashima, T. Imai, and T. Yoshimi (*Nippon Kinzoku*, 1959, **23**, Sept., 526–530) Variations of the peak with quenching temp. are described. They indicate that C concentrates along the sub-boundaries and grain boundaries, and is probably responsible for α-veining and grain boundary ridging. In specimens freed from these phenomena in various ways the broadened peak is the sum of the normal C and N peaks (15 refs).—K.E.J.

The relation between heat-treatments and the room-temperature internal friction of some carbon steels G. Mima and M. Mizuta (*Nippon Kinzoku*, 1959, **23**, Aug., 469–473) Measurements were made using transverse vibrations of ~1·85 kc/s. The internal friction of martensite specimens is proportional to C content, and is caused by stress induced by diffusion of C. A two-stage change in tempering of martensitic specimens is interpreted by pptn. of C as ε-carbide and cementite. In annealed specimens containing coarse free ferrite, the amplitude-dependent internal friction is caused by magneto-mechanical hysteresis (27 refs).

Study of methods by non-destructive measurement of residual stress F. R. Rollins (*WADC Techn. Rept.*, 59–561; *PB* 161436, 1959, Dec., pp.48; from *US Res. Rep.*, 1960, **33**, May 13, 549) It has been definitely established that residual stresses in metals can cause double refraction of a polarized shear wave. A technique, based on the double refraction of shear waves, for measuring the average stress through certain specimens is described, and sources of error are discussed. The interaction of two ultrasonic waves in metals has also been investigated.—S.H.-S.

The behaviour of grain boundaries in metals in a temperature gradient R. W. Cahn and R. W. Lucas (*AFOSR–TR–59–126*; *AD–230161*; *PB* 145664, 1959, pp.45; from *US Res. Rep.*, 1960, **33**, June 17, 669) The appropriate conditions for grain boundary motion are indicated.—S.H.-S.

Initiation of slip in silicon–iron J. Holden (*Acta Met.*, 1960, **8**, July, 424–430) Observations on the deformation of silicon–iron crystals containing small precipitates surrounded by clusters of dislocations are presented. Slip bands are observed to develop from the clusters, and two mechanisms are distinguished.—S.H.-S.

Interactions between glide dislocations in a double pile-up in α-iron Y. T. Chou, F. Garofalo, and R. W. Whitmore (*Acta Met.*, 1960, **8**, July, 480–488) From the equilibrium distribution of dislocations, calculation is made of the stresses near the tip of the double pile-up, and for 50 dislocations the shear stress at the tip is calculated to be 1360 σ_a, where σ_a is the applied stress in the slip plane, this stress being greater by a factor of 27 than the tip stress of a single pile-up of the same size. The high stress concentration at the tip of a double pile-up confirms Cottrell's suggestion that such a dislocation arrangement could initiate cleavage cracks in α-iron.—S.H.-S.

Activities in liquid and solid metal systems J. F. Elliott (*AECU*–3864, 1958, Oct., pp.9; from *Nucl. Sci. Abs.*, **13**, Feb. 28, 279) Brief summaries of experimental work being done in the phase distribution of Fe–Ni–Pb, Fe–Ni–Pb–C, and Fe–Ni–C systems at 1350–1550°C are presented. In addition activities in the Al–Ag–Pb, Mn–Fe, and Mn–Fe–Pb systems at 700–1100°C were investigated. Results are represented graphically.

On the application of phase diagrams to the understanding of thermo-dynamic interactions E. Bonnier and P. Desré (*Compt. Rend.*, 1960, **251**, Aug. 1, 706–708) The direction of curvature of the liquidus in the neighbourhood of the pure metals in a binary system gives information on the modes of reaction of the liquid metals.

Thermodynamics of the chromium–iron system O. Kubachewski and G. Heymer (*Acta Met.*, 1960, **8**, July, 416–426) A method for the determination of the vapour pressure of Cr has been devised by combining Knudson's effusion method with tracer analysis using ^{51}Cr of half-life 27·8 days. The vapour pressures determined in the temp. range 1170–1400°C agree with previous work and may be represented by the equation $\log p\,\text{atm} = -19700/T + 6{\cdot}92$. The heat of sublimation at 298°K is 94·0 kcal/g-atom, the boiling point is estimated to be 2680°C. The Cr pressures in the system Cr–Fe have been measured at 1340–1370°C for various compositions. The activity curve shows some deviation from Raoult's law. Phase boundaries have been calculated and found to agree essentially with the experimental phase diagram.—S.H.-S.

The effect of atomic ordering on exchange interactions of the Fe_3Pt alloy K. P. Belov and Z. D. Sirota (*Eksp. teoret. Fiz.*, 1959, **36**, (4), 1058–1062) Measurements have been carried out on the dependence of magnetostriction and temp. in an alloy nearest to the Fe_3Pt composition and the displacement of the Curie points under the influence of pressure and spontaneous lattice deformation are calculated. It has been established that the atomic ordering in the Fe_3Pt alloy changes not only the magnitude of exchange interactions but also the nature of its dependence on interatomic distance.

The compression on fracture of tensile test pieces A. Krisch (*Arch. Eisenh.*, 1960, **31**, Aug., 491–496) A damped oscillation occurs in a tensile test piece on fracture, which can lead to residual compression in special cases; up to 0·8% compression has been measured on steels in the tensile strength range of 44–94 kg/mm^2 (15 refs).

A classification of the cases of deformation of metal bars subjected to an extension force J. Wantuchowski (*Arch. Hutn.*, 1960, **5**, (1), 61–104) Tests were carried out under static tensile loading. The paper is based on two observed relationships: the sum of the rates of motion of the pointers indicating loading and extension remains constant during the test, and that there are spontaneous natural increases of extension and falling of load in rods strained beyond the elastic limit. The author then describes the various ways the machine can be used and in fact the purpose of the article is to introduce the author's method of notation for this type of work. He employs a system of triangles and squares, the triangle expressing the external influence of the machine and the square spontaneous change.

Investigating the resistance to deformation of carbon and alloy steels under tensile stresses and shrinkage G. A. Khasin and V. N. Davidyuk (*Stal'*, 1960, (10), 953) A note from Zlatoust. Tests on 18 steels have been carried out between 800–1250°C at various tensile and compressive deformation rates. Some steels showed a maximum, others a progressive rise.

Low temperature tensile-hardness correlations of SAE 4340 steel J. Nunes and F. R. Larson (*WAL–TR*–320, 4/1; *PB* 161467, 1960, Feb., pp.19; from *US Res. Rep.*, 1960, **33**, June 17, 670) Vickers hardness (DPH) and tensile strength (UTS) on one heat of SAE 4340 steel proved linear with respect to the reciprocal absolute temp. Simple empirical equations for calculating approximate values of DPH or UTS with range studied can be derived.

Methods for conducting short-time tensile, creep, and creep-rupture tests under conditions of rapid heating D. P. Moon and W. F. Simmons (*DMIC rept.* 121; *PB* 151078, 1959, Dec., pp.43; from *US Res. Rep.*, 1960, **33**, June 17, 673) The equipment and methods of testing used by 15 different organizations are reviewed and relative merits of alternative techniques are discussed.—S.H.-S.

Resistance to thermal stress fatigue of some steels, heat-resisting alloys, and cast irons H. G. Baron and B. S. Bloomfield (*JISI*, 1961, **197**, March, 223–232) [This issue].

METALLOGRAPHY

On the methods used in stereometric metallography. II J. Likeš (*Hutn. Listy*, 1960, **15**, (7), 538–545) The paper deals mainly with the theory and practice of particle size determination, i.e. of grains or dispersed phases, by means of line intercept measurements.—F.F.

On methods of stereometric metallography. III J. Likeš, J. Cadek, K. Mazanec, and J. Kudělkova (*Hutn. Listy*, 1960, **15**, (8), 615–619) The theory underlying the determination of the number and magnitude of dispersed disc-shaped particles from micrographic data and measurements, is developed. It is used to show that the shape of bainitic particles changes during their growth.—F.F.

A contribution to electron microscopical fractography M. Molčík (*Hutn. Listy*, 1960, **15**, (8), 625–628) Fractures in several carbon steels were studied by means of a two-stage celluloid/carbon replica method developed by the author.—F.F.

The structure and density of iron films formed by thermal evaporation O. S. Heavens, M. M. Brown, and V. Hinton (*Vacuum*, 1959, **9**, March, 17–20) Iron films deposited on rock salt at 470°C were examined by electron microscopy and found to be monocrystalline and continuous. The density was that of the bulk metal.

Automatic polishing technique for electrothinning metals for transmission electron microscopy V. A. Phillips and J. A. Hugo (*J. Sci. Inst.*, 1960, **37**, June, 216–218) This article describes a method of automatic electropolishing which is an improvement on other methods where the sample cannot be observed during polishing, edge attack occurs, and fragments become entrained in the electrolyte and become etched. The instrument used—a Disa-Electropol type 53A, is designed to overcome these disadvantages.

Investigation of the etch pattern of the grain boundaries of various steels with the interference microscope R. Pusch and P. Schwaab (*Arch. Eisenh.*, 1960, **31**, Sept., 563–565) Investigation of 'doubled' grain boundaries by oblique illumination showed that Böschung surfaces were present in all cases. The theoretical considerations due to Engell on the structure of the grain boundaries as a function of the orientation of adjacent grains were confirmed.

The morphology of martensite P. M. Kelly and J. Nutting (*JISI*, 1961, **197**, March, 199–211) [This issue].

The effect of up-quenching on the kinetics of bainite formation J. S. White and W. S. Owen (*JISI*, 1961, **197**, March, 241–243) [This issue].

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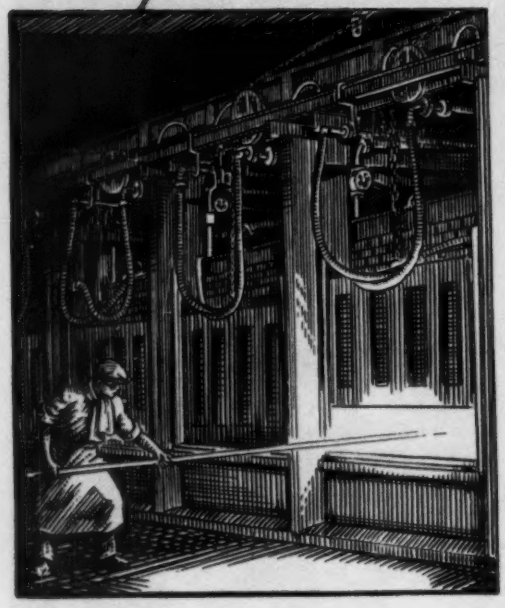

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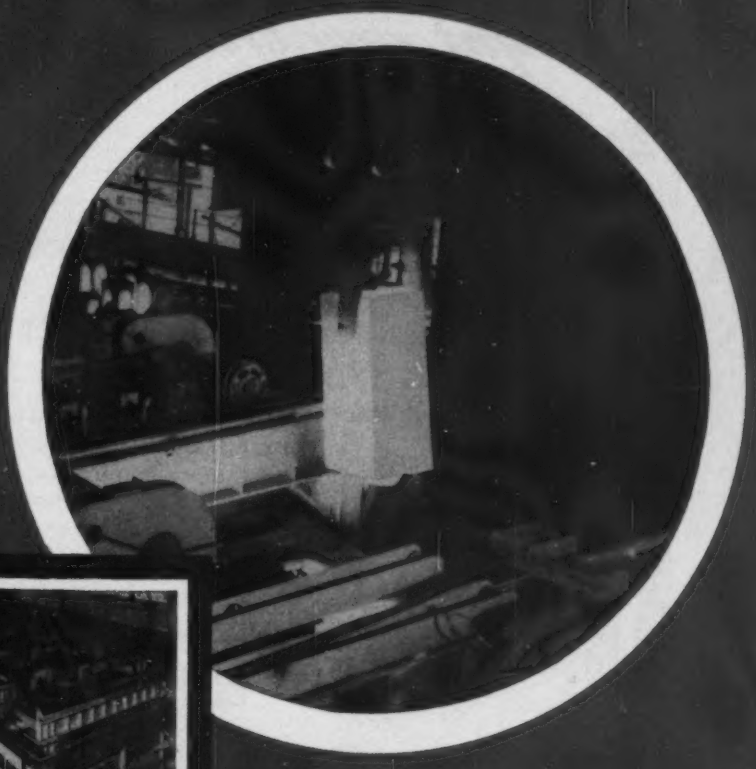

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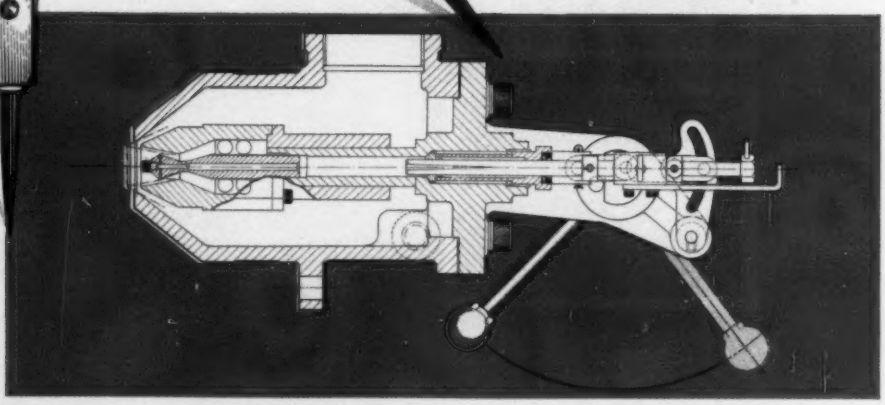

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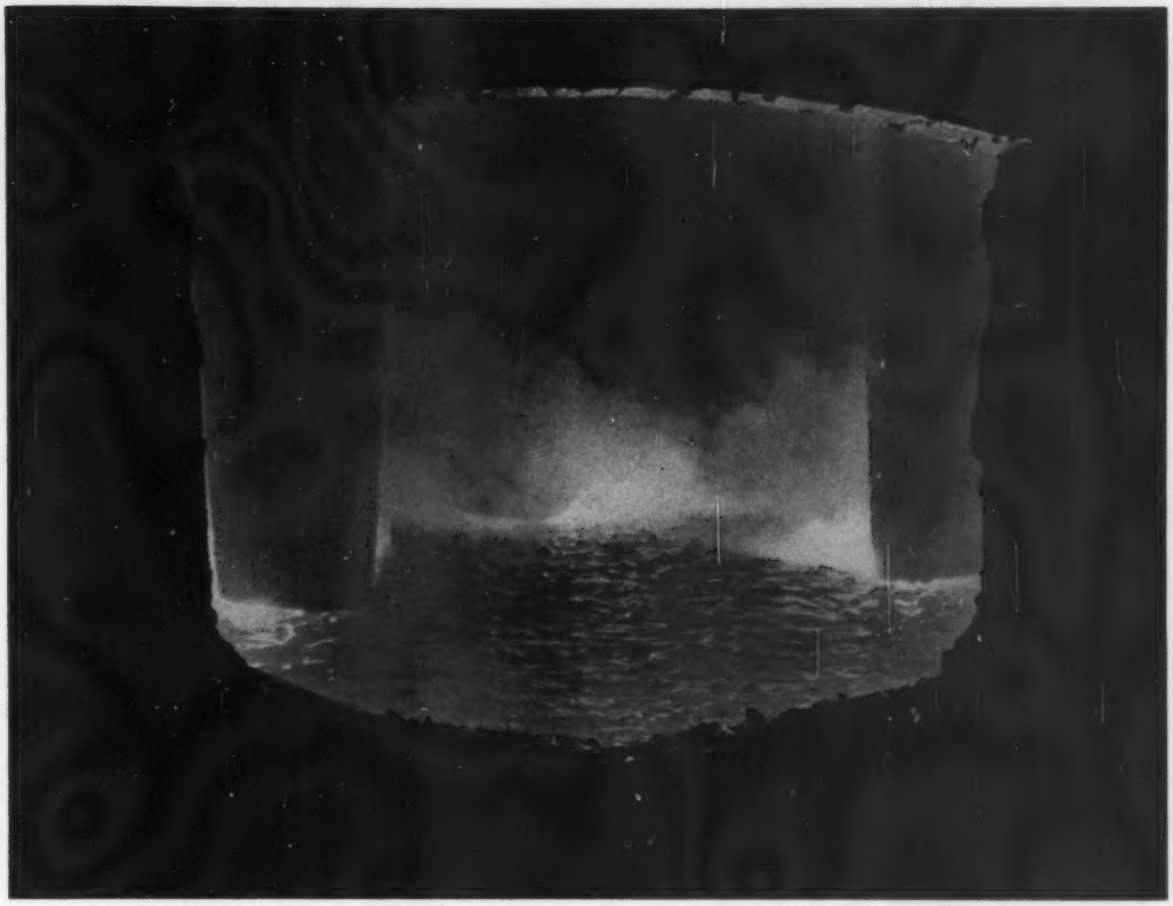

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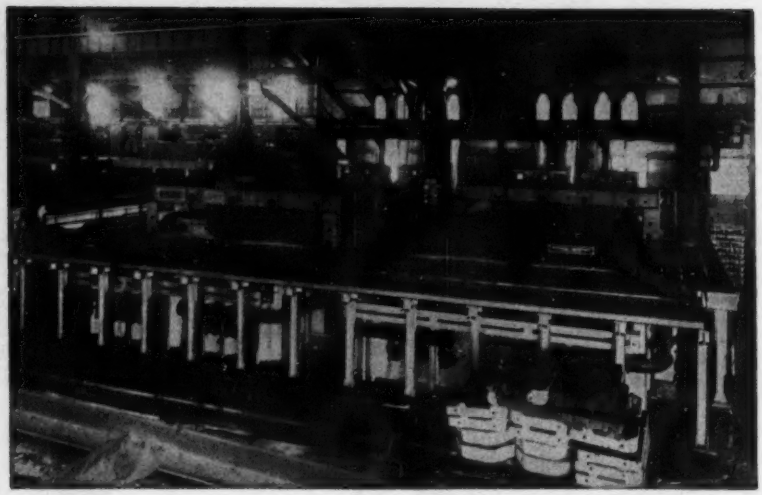

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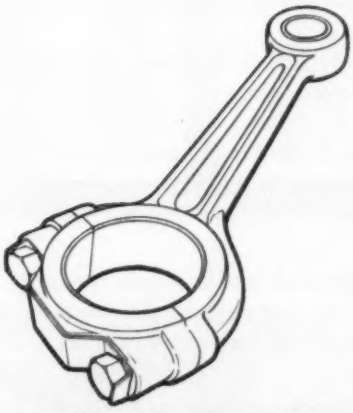

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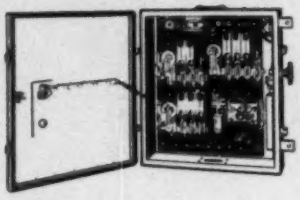

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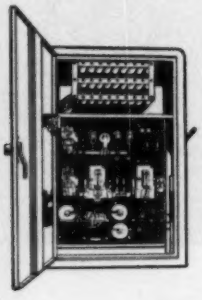

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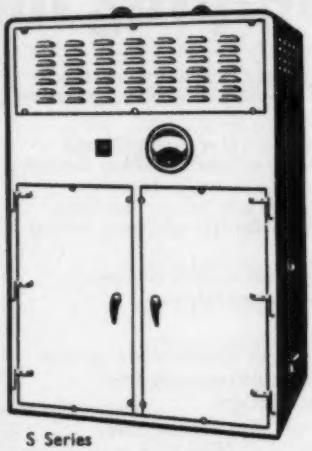

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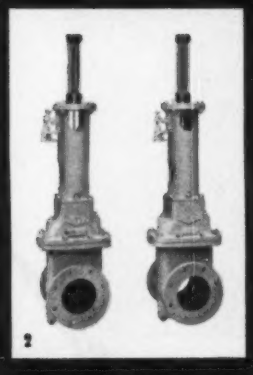

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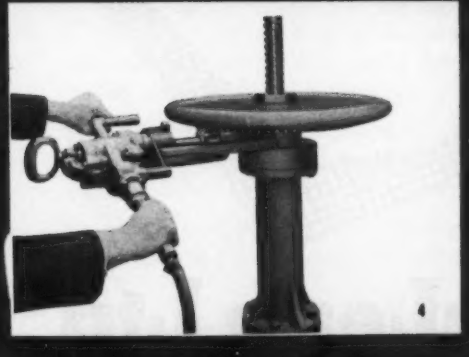

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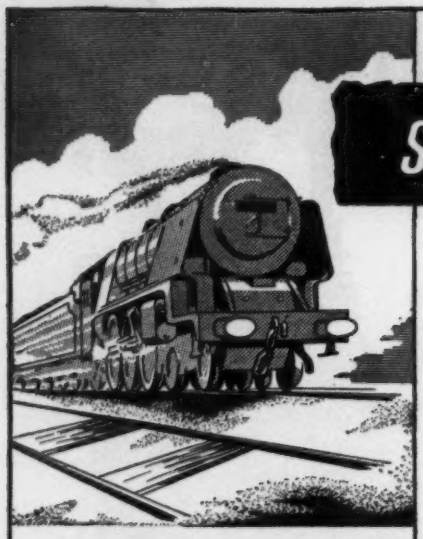

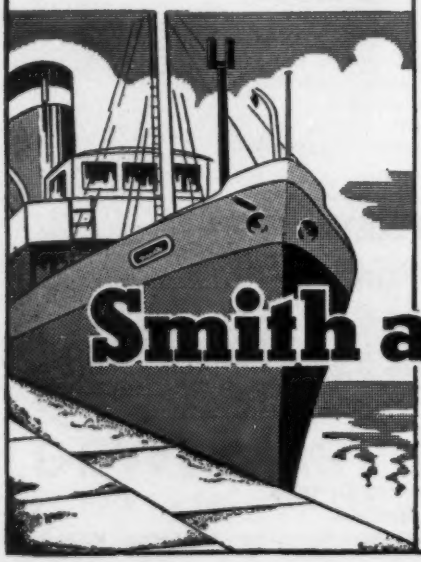

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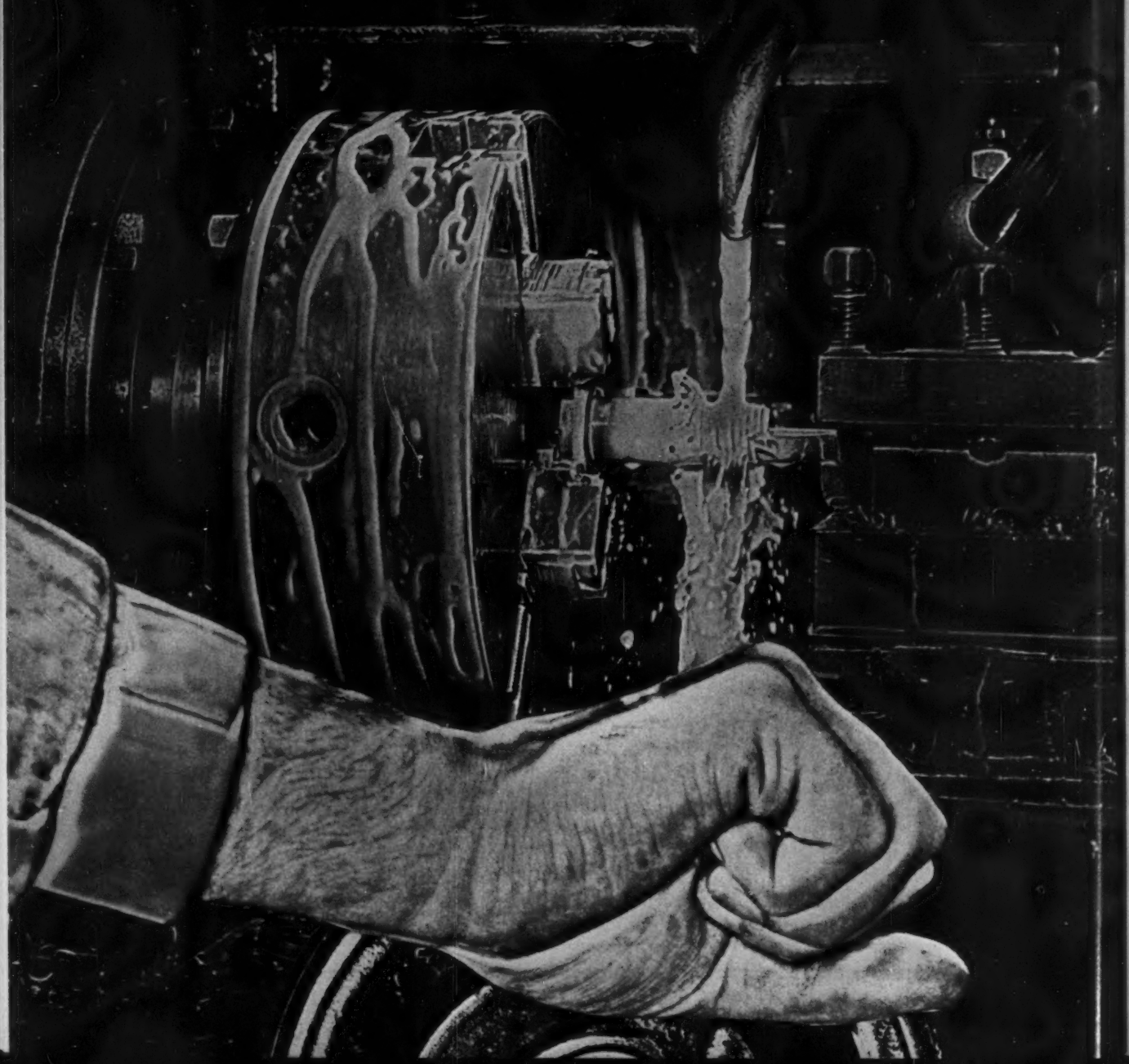

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Shell research chemists have been working on this problem, which has been causing some concern to Management. After considerable research, Shell Dromus Oils have been reformulated and these new cutting oils now produce bland emulsions, which considerably reduce the risk of skin trouble to operators.

The real difficulty was to find a new coupling agent to replace the phenolic compounds, and Shell finally used what their chemists know as a higher fatty alcohol complex. This solved one problem, but presented another. The new coupling agent was volatile at the high temperatures normally used in blending processes. Further research found a solution to this problem by designing and installing new plant.

The new Dromus Oils are every bit as efficient as before and cost no more. They put Management in the welcome position of being able to minimise working hazards at no extra cost. And machine men need no longer be so worried about skin troubles.

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The Research Story

Shell chemists in the U.K., in Holland and in the U.S.A., prepared and examined hundreds of experimental soluble oils, and established that certain combinations of fatty alcohols could be used in place of phenolic compounds with no loss of efficiency. They set to work to discover the best combination and developed a higher fatty alcohol complex which fitted exactly. Then they realised that to blend this new coupling agent into soluble oils would require special plant and new blending techniques.

Exhaustive testing of blend stability, emulsion stability, anti-corrosion and machining properties led to selection of the most promising blends. A pilot plant was set up to produce batches of these for use in field trials.

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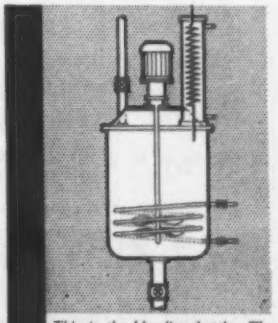

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Production of wide steel strip

I.S.I. Special Report 67

As part of its Annual General Meeting in May 1960, The Iron and Steel Institute held a three-day symposium in London devoted to *Production of wide steel strip*, a subject of great topical interest. More than 250 people from Europe and America attended this symposium and took part in the excellent discussions.

Sixteen papers by authors from Australia, Italy, the Netherlands, the United Kingdom, and the U.S.A. were presented at the five technical sessions, which were devoted to the future requirements of the user industries, steelmaking for wide strip production, hot rolling, cold rolling and heat-treatment, and coatings on strip respectively. All the papers have now been gathered together, with a full report of the discussions, in No. 67 of the Institute's Special Report series. There is a provocative foreword by the President of the Institute, Mr W. F. Cartwright.

The report is a quarto volume, comprising 196 pages. It is printed on imitation art paper and is fully illustrated with 98 line diagrams and graphs and 57 photographs. Copies may be obtained, price 65*s*. each (plus 1*s*. postage) from the Secretary of the Institute at the address given below.

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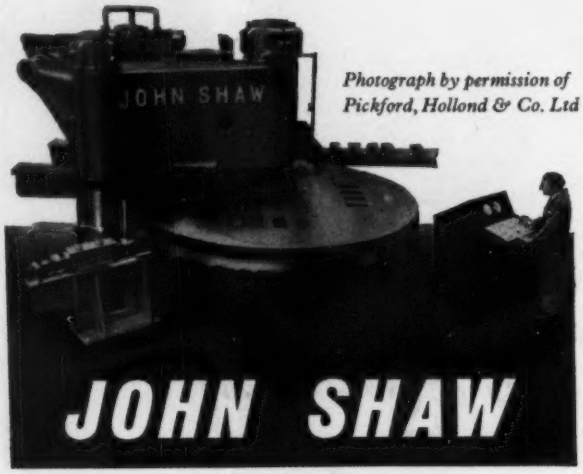

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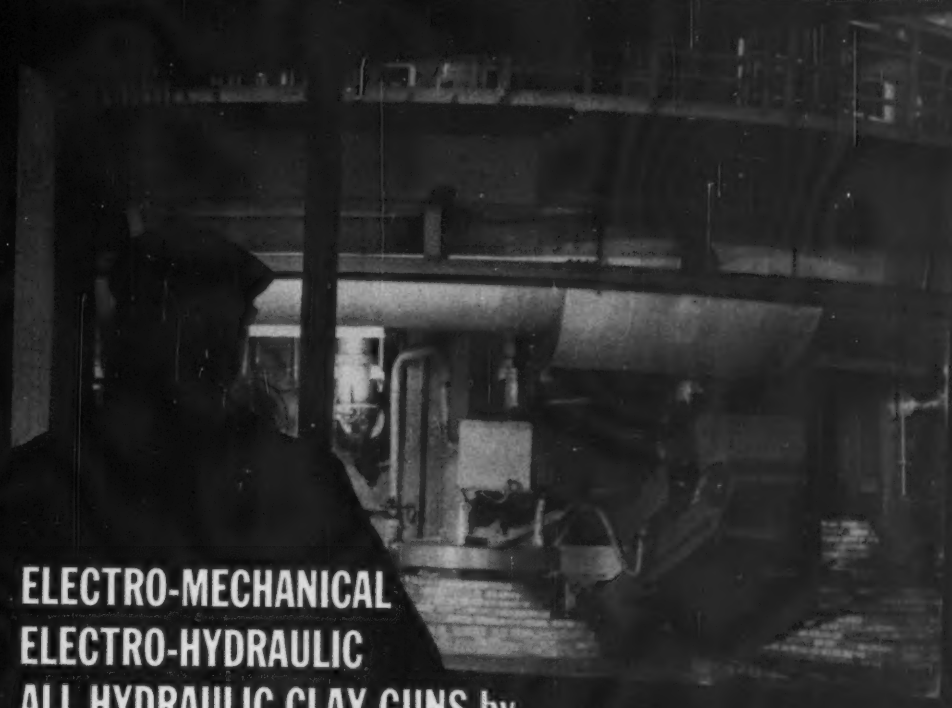

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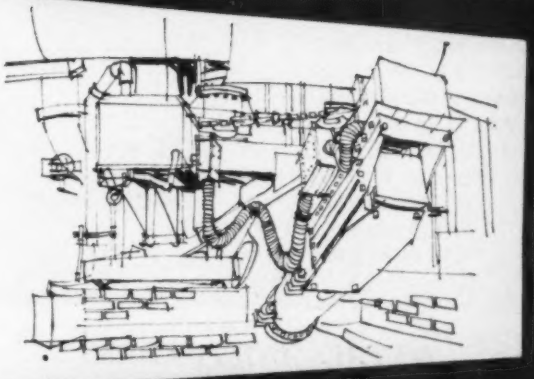

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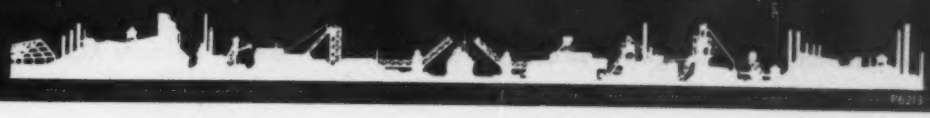

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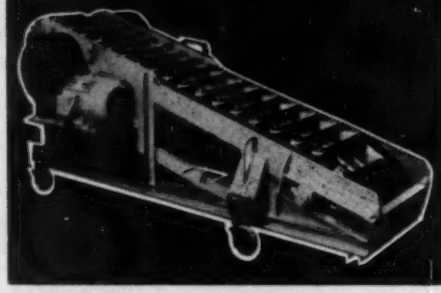

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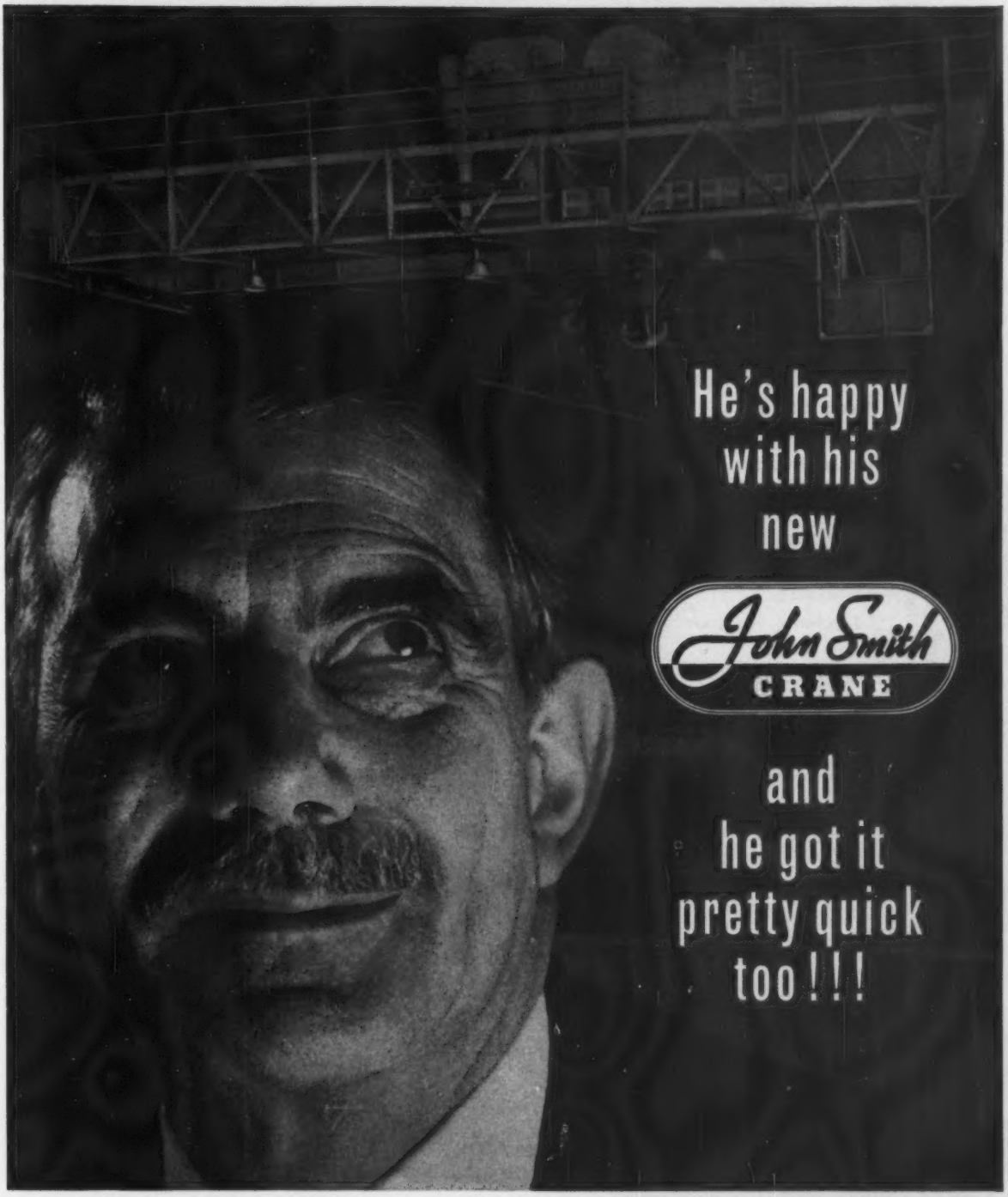

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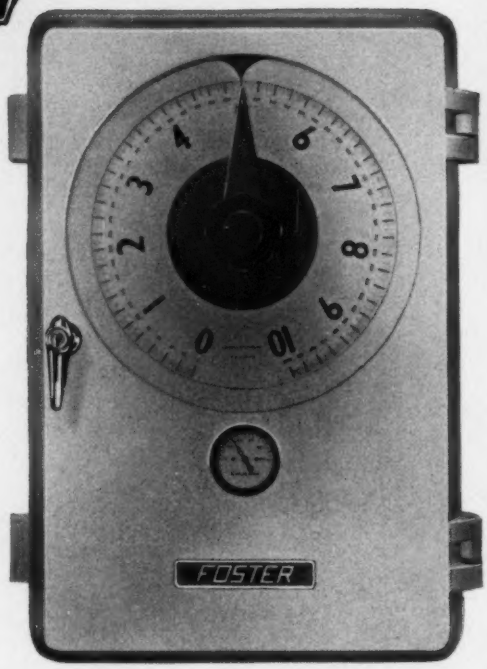

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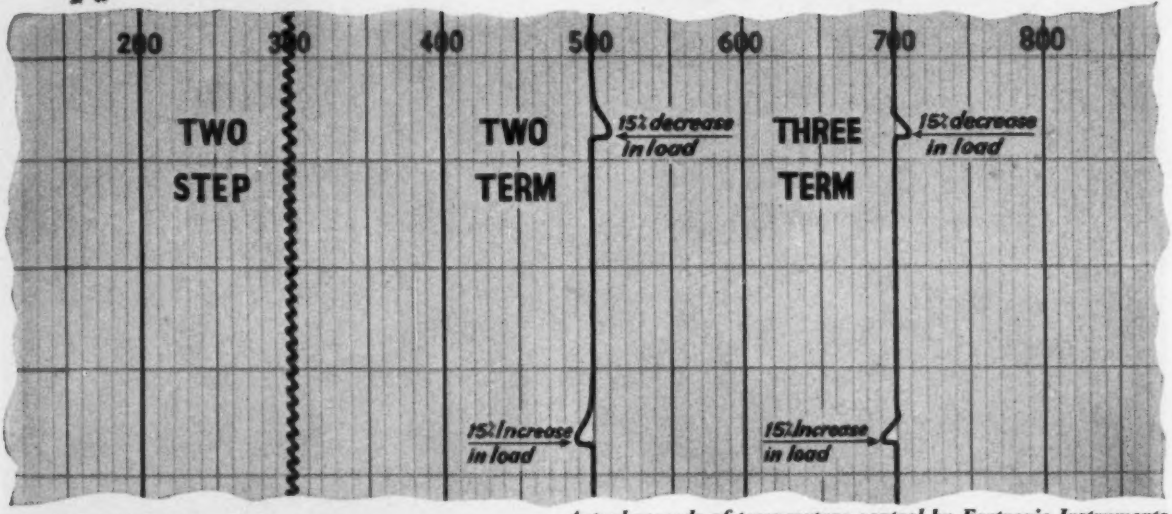

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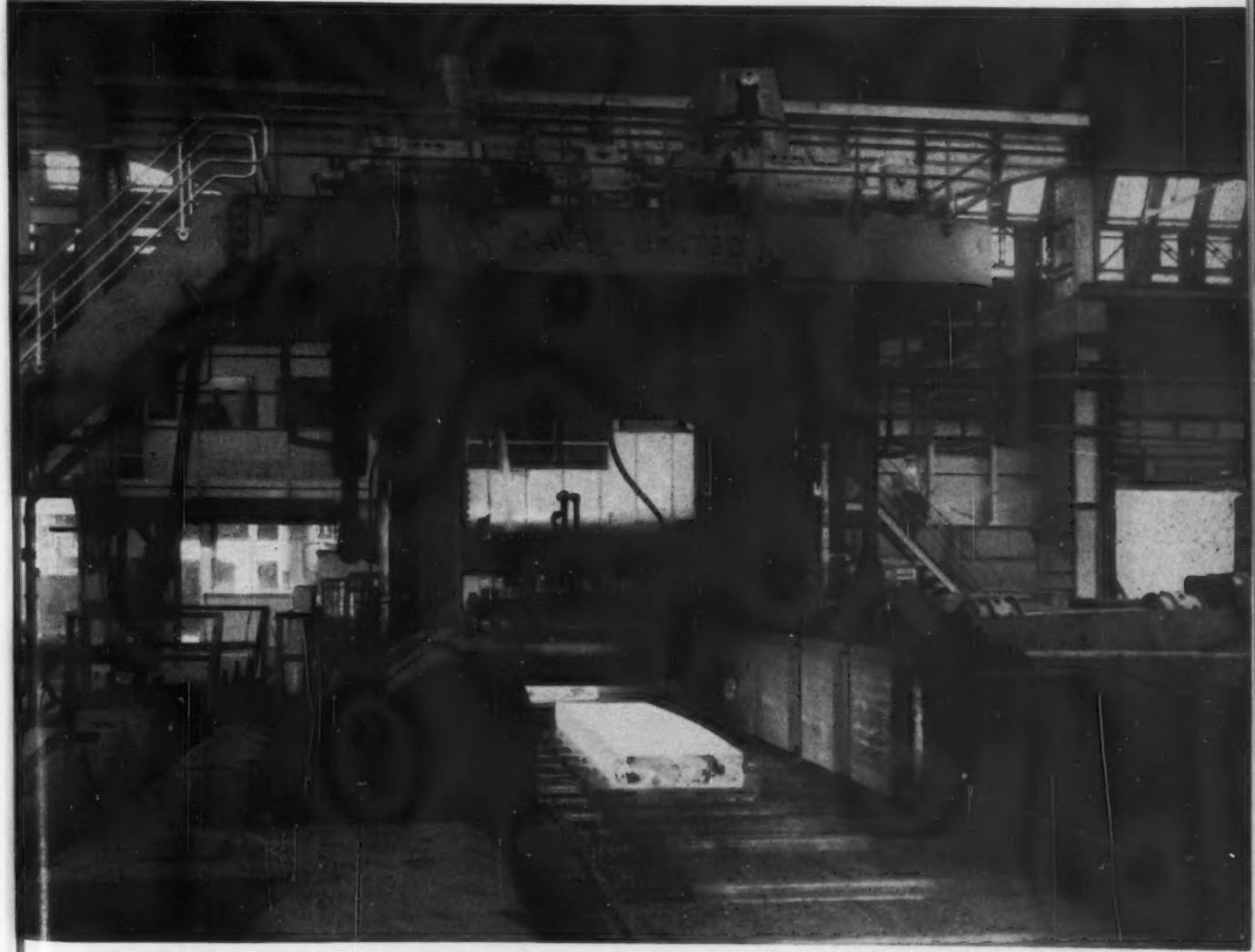

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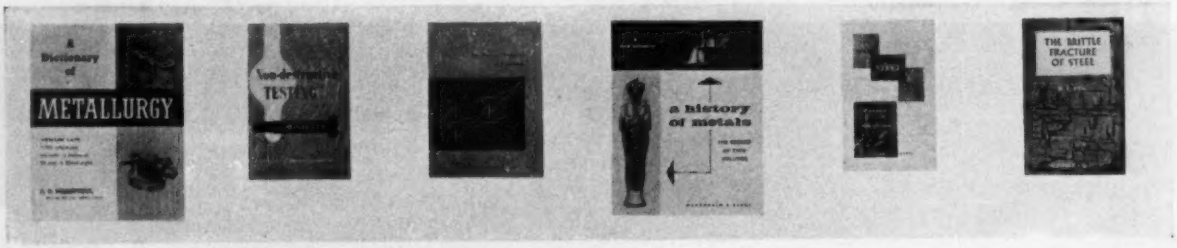

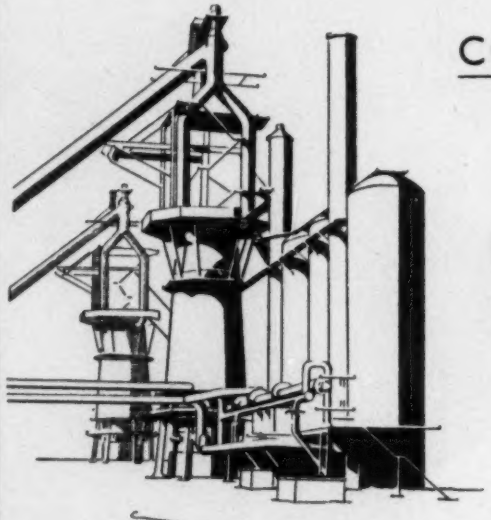

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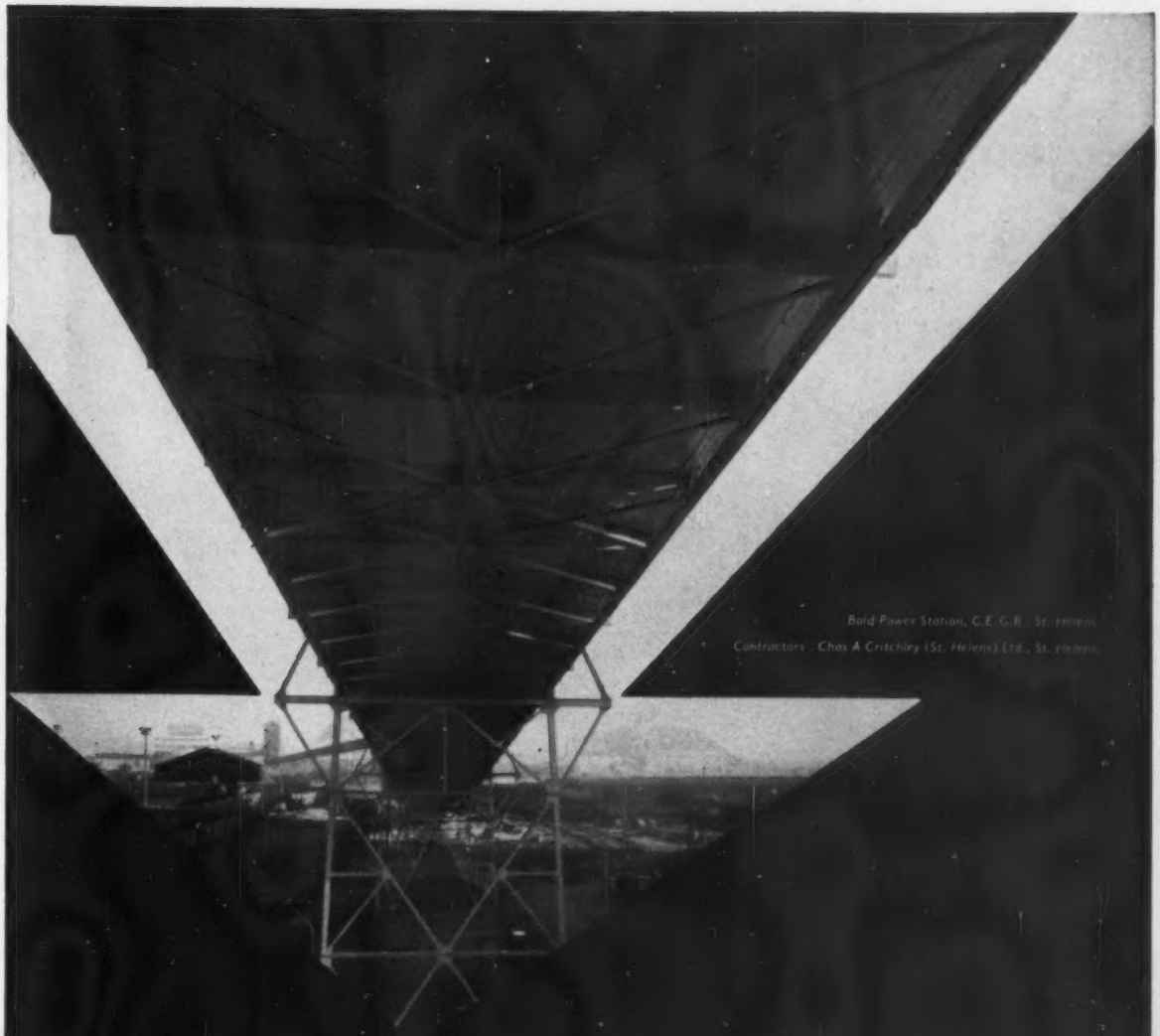

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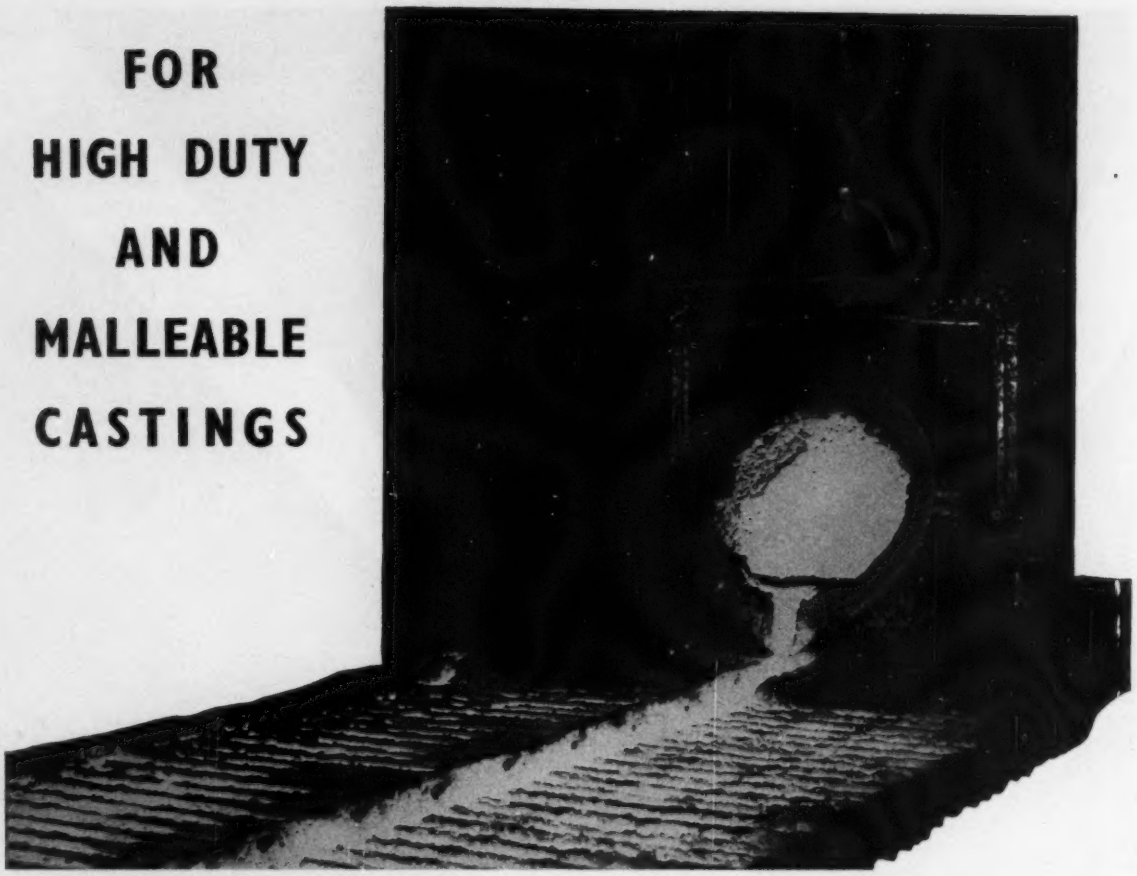

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PHOSPHORUS%	0·6–0·7	0·6–0·7	0·6–0·7	0·4–0·5	0·25	0·25	0·25
MANGANESE%	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5
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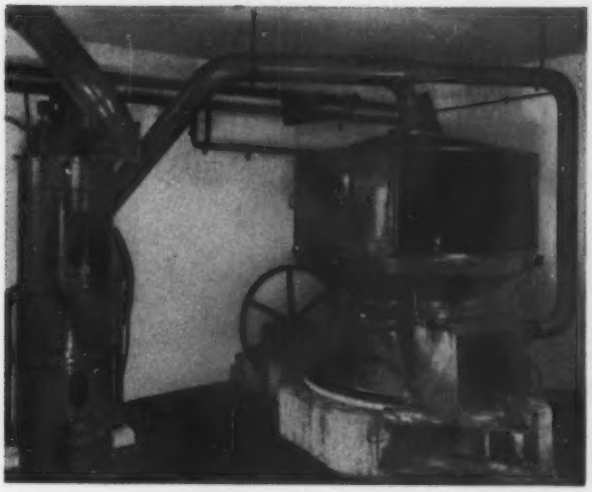

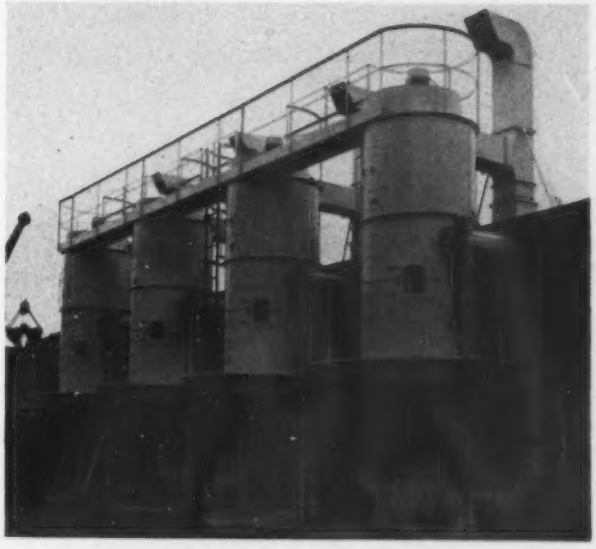

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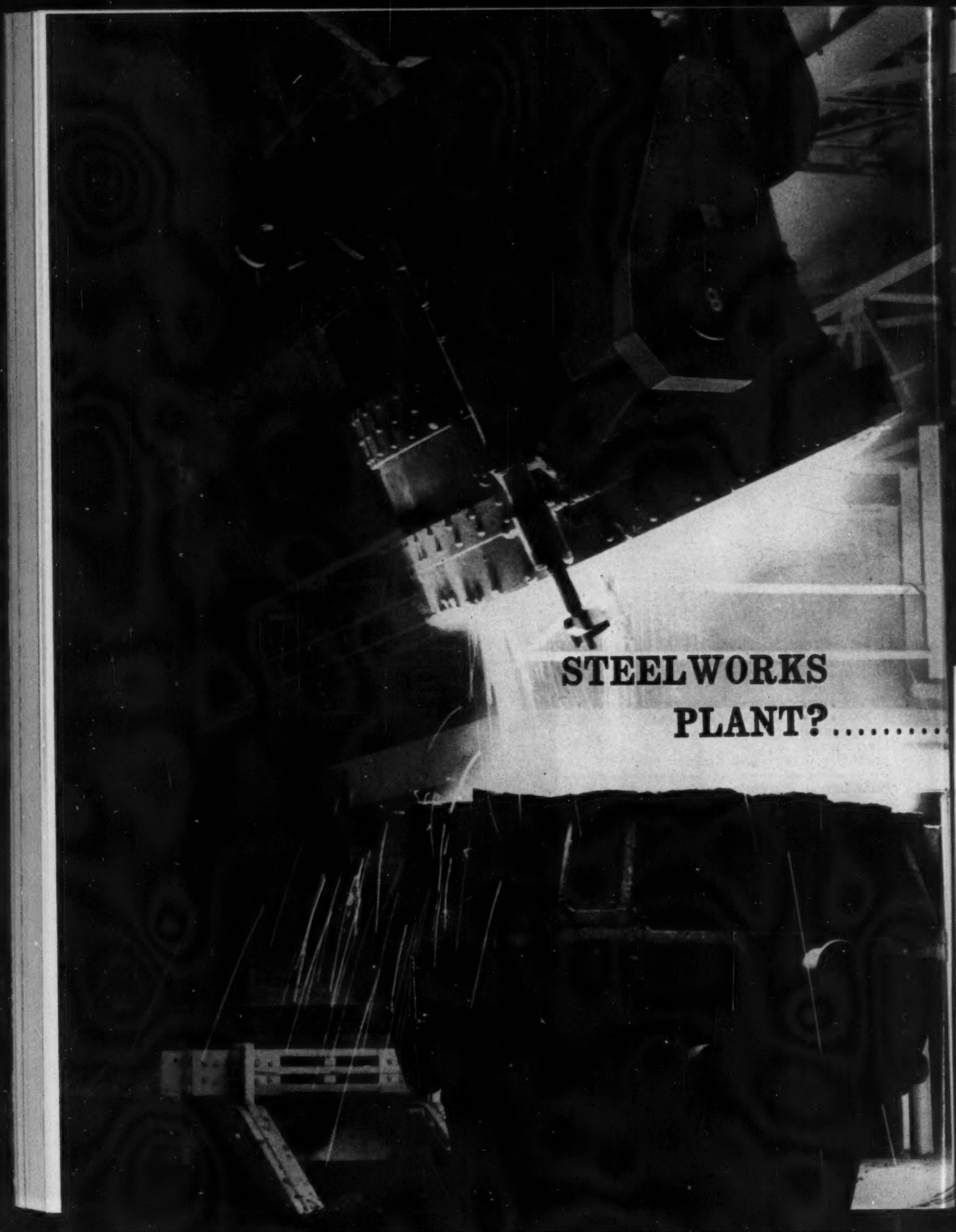
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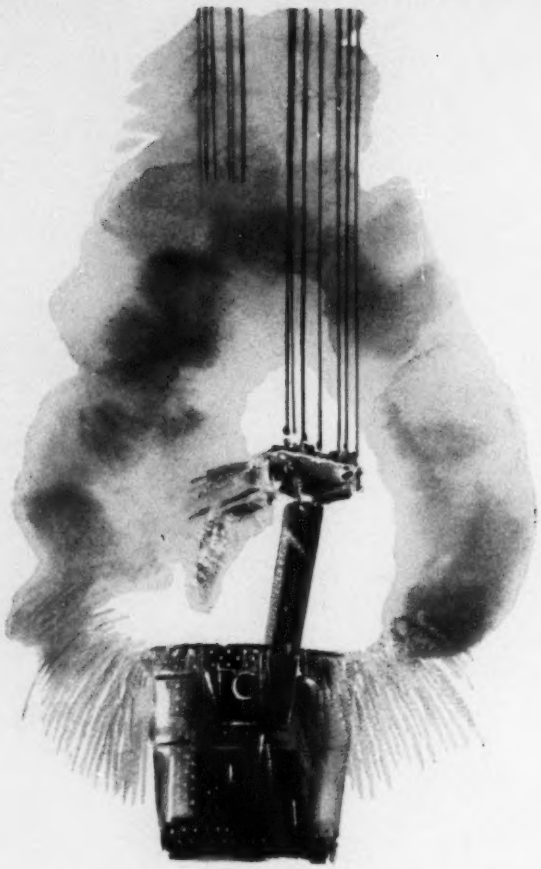

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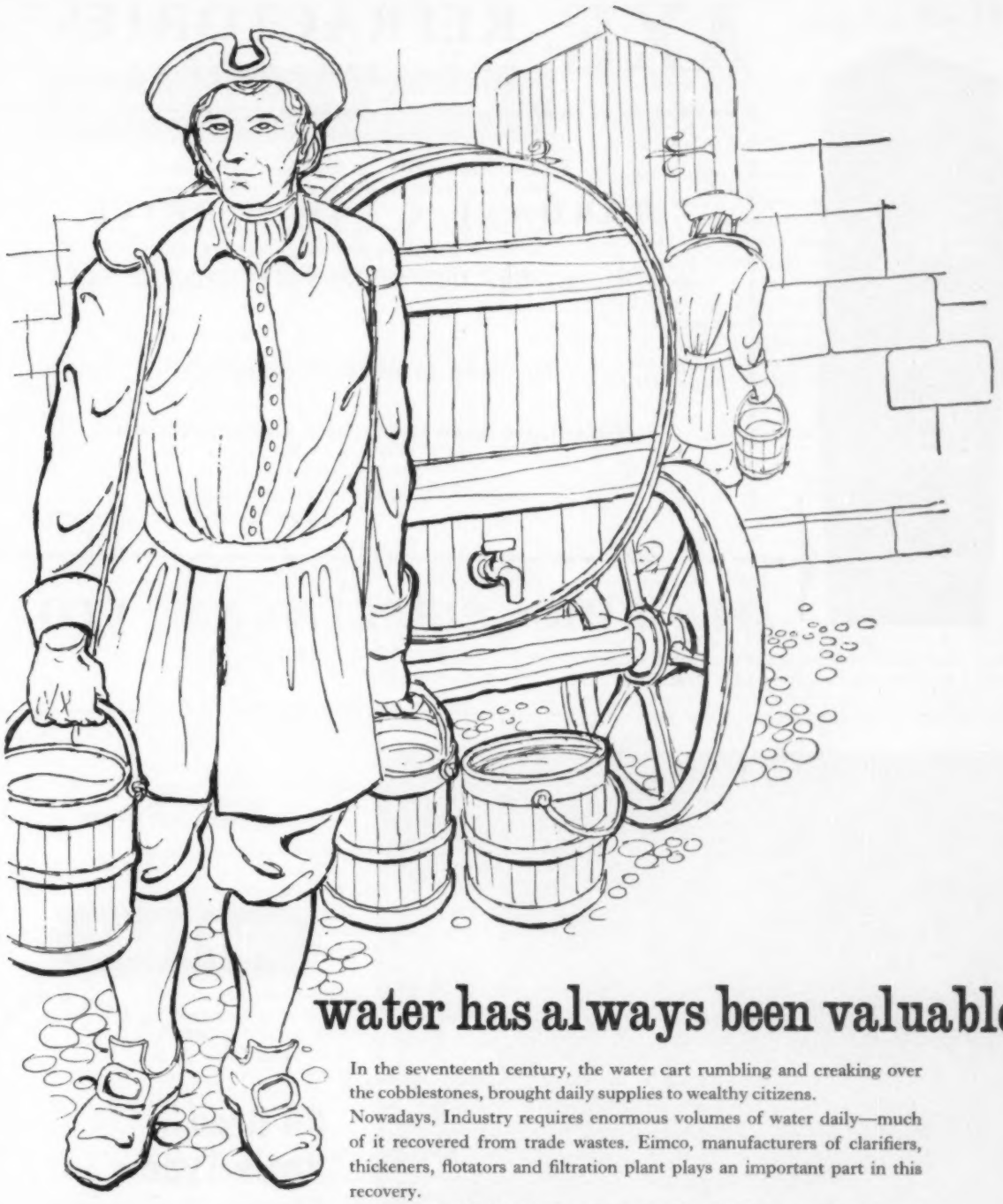

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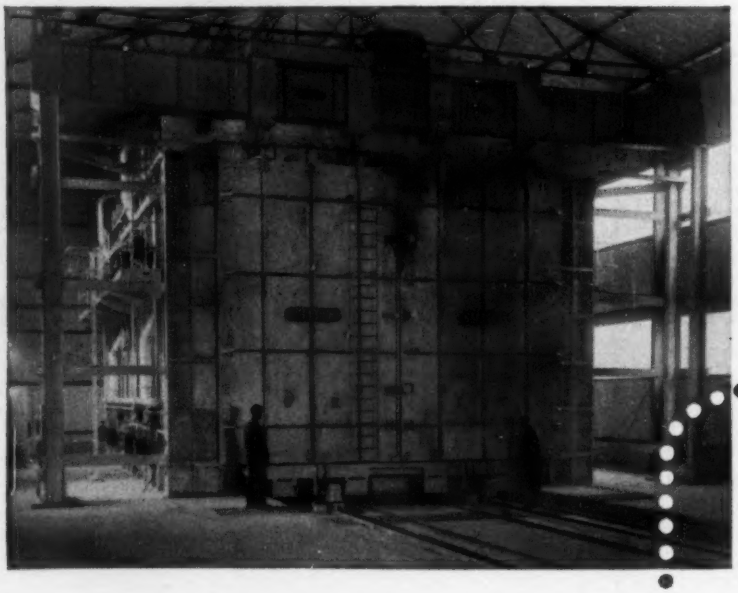

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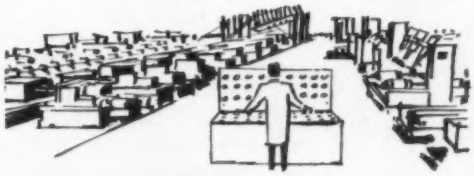
Electrical Aids in Industry — *Data Sheet* **No.15**

Electric Motors & Controls-2

Control equipment must enable the motor to be operated effectively, to obtain maximum productive efficiency of a given machine. An outstanding advantage of individual electric drives is the flexibility of control available. Control equipment may be manual, semi-automatic or fully automatic, and includes gear for the following operations:

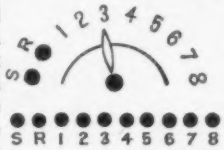
(a) Starting
(b) Speed Control (this subject will be dealt with in Data Sheet No. 16)
(c) Reversing
(d) Stopping
(e) Switching off automatically if operating conditions become abnormal
(f) Isolation of motor and control equipment from the supply.



Every application of power has its own particular control requirements—and they are legion. Below are featured four uses of electric motors and their controls; they are given only as examples and represent but a small fraction of the whole picture.

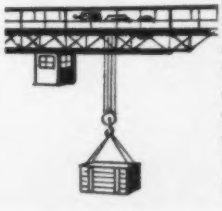
Turret-lathe Control

Various speeds are required for different tools, and it is possible to arrange, for instance, for a four-speed headstock, forward and reverse, incorporating a power-operated pre-selector speed change. By using a two-speed double-wound motor, eight speeds forward or reverse are obtainable. A dial on the headstock is set to the required speed and when a knob in the centre of the dial is pressed, the power-operated mechanism changes the speed instantly.



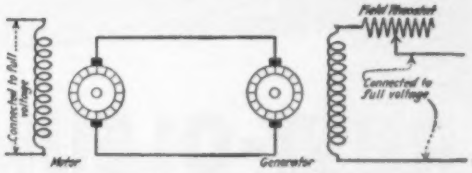
Crane Control

This is a form of control which must be flexible yet completely foolproof. It is, for instance, possible to arrange for motor switching to be performed by contactors in response to movement of the crane driver's master controller which has a number of notches, each of which is associated with a particular set of contactors for acceleration, speed control, reversing and braking. If the controller is moved quickly from the 'off' position to the 'last point lowering', the rate of acceleration is limited automatically by the relays. These also govern the retardation in order to prevent a heavy descending load being stopped too suddenly. This is just one of the ways in which electric control mitigates the hazards of crane operation.



Planing-machine Control

Another example of motor control for machine tools is that for planing machines. For general workshop machining, the Ward-Leonard controlled motor, with a speed range of 10 to 1, gives a rapid and smooth reversal of the table travel and is ideally suited for short-stroke work. Two arrangements of Ward-Leonard control are available, the 3-machine set with generator, exciter and driving motor, and a specially designed 4-machine set with an additional auxiliary exciter. With the 3-machine set the control



equipment can include magnetic time relays which automatically adjust a regulator to strengthen the motor field at the instant of reversal and therefore greatly increase the accelerating torque. The auxiliary exciter of the 4-machine set automatically provides 'field forcing' on the generator; in other words, the power input to the motor is increased to give more accelerating torque at the instant of reversal.

Automatic Control

The control equipments described incorporate automatic features which help considerably towards obtaining safe and efficient operation of the driven machine, but much still depends on the human element. Braking equipment, for instance, cannot always become effective until an operative has taken some action. In an emergency this physiological time lag which delays the initial action will also delay the final effect. Fortunately it is often practicable to employ devices, which will be described in other Data Sheets, to 'observe' any abnormal condition and immediately and automatically to initiate the braking system.

Particular attention should be paid to the positioning of controls. When a machine, or group of machines, requires a large number of push buttons and, in some cases, instruments, etc., the controls can be grouped on a desk with a mimic diagram, located in a position where the operator has full view of the work.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. TEMple Bar 9434.

They can offer you excellent reference books on electricity and productivity (8/6, or 9/- post free)—'Electric Motors and Controls' is an example.

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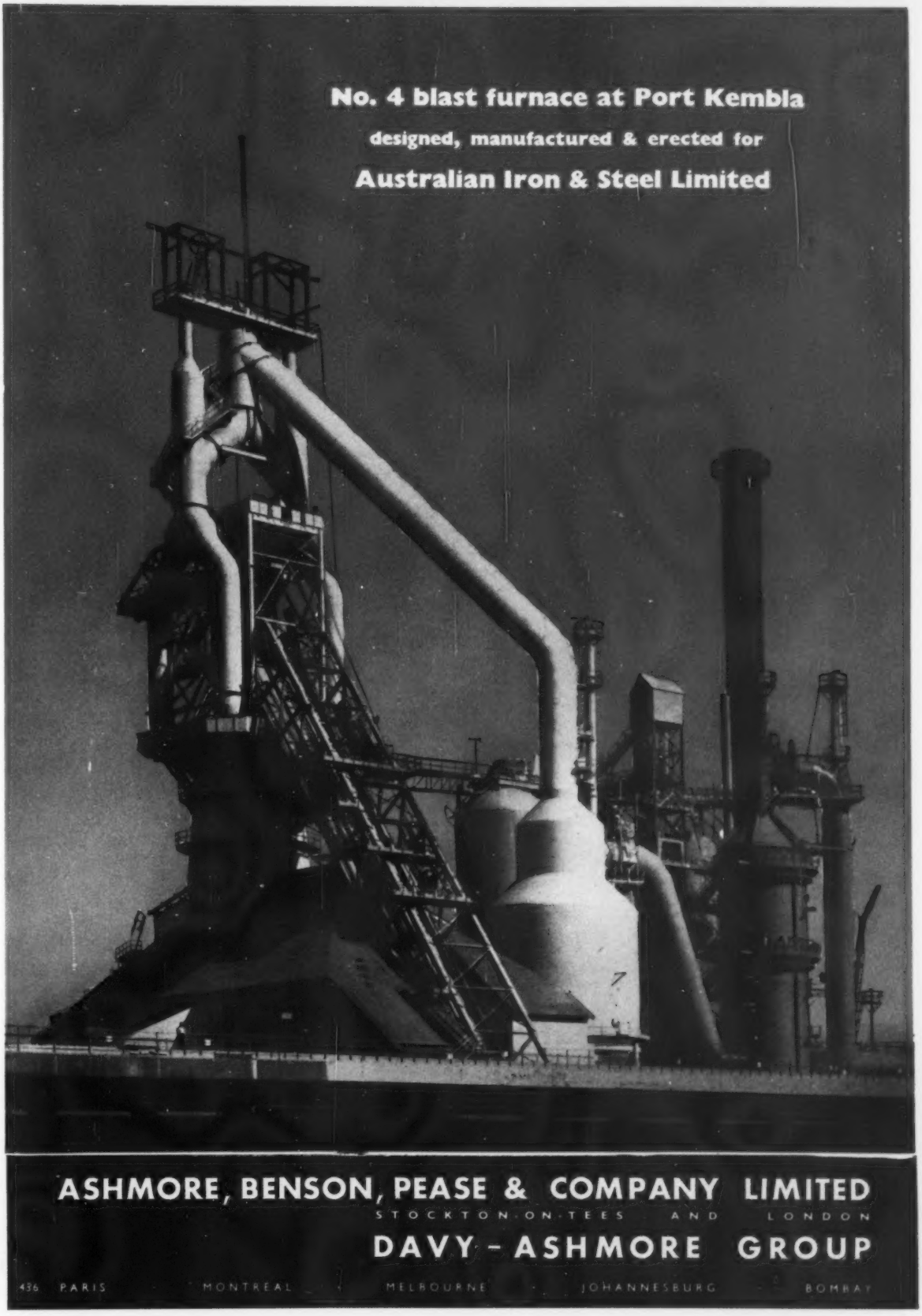
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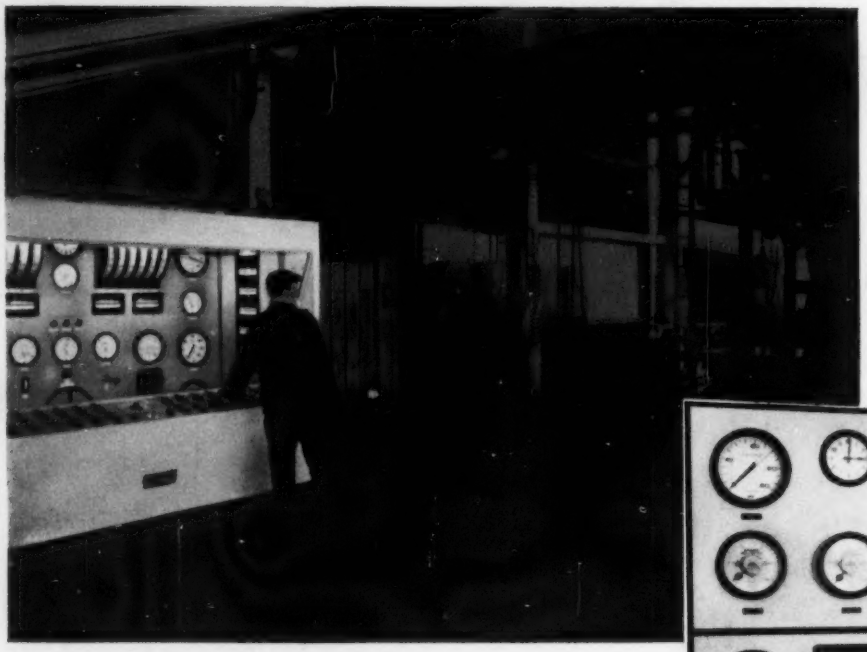

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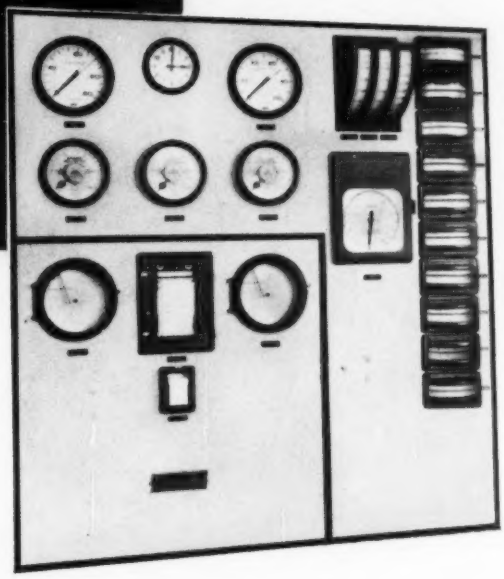

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